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OLD MOTHER EARTH

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Figure 1. Glaciers such as these on the flanks of Mount Robson in the Canadian Rockies assisted in the sculpturing of the surface of Old Mother Earth in many mountainous regions during the Great Ice Age.

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OLD MOTHER EARTH

BY

KIRTLEY F. MATHER

PROFESSOR OF GEOLOGY IN HARVARD UNIVERSITY

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TO

MARIE PORTER MATHER

COMPANION AND OFTTIMES GUIDE
IN THE QUEST OF TRUTH

14629

PREFACE

SUMMONED to "the conscious adventure of humanizing knowledge," the geologist is often surprised by the large number of persons interested in the lore of minerals, rocks, and fossils. We are learning that, to comprehend life, we must among other things know something of the past history of the planet on which we live. This widespread interest in the science of geology was impressed upon me by the request to deliver a series of radio talks from Station WEEI at Boston during the winter of 1927–1928.

The radio is an exacting master. Debarred from the use of blackboard, stereopticon illustrations, or charts, the speaker must depend solely upon words to convey ideas and create mind-pictures. Limited to a few minutes of specified time, he must plan his statements carefully to make the best use of valuable seconds. Each talk must be complete in itself and must fill precisely the allotted interval, no more, no less.

This little volume is a result of the attempt to meet these requirements. Its successive chapters were first prepared for broadcasting to an unseen and unknown audience. They have since been somewhat modified and

rearranged for the reader rather than for the listener. Illustrations have been added to clarify the discussion.

I am deeply indebted to many colleagues and publishing houses for constructive criticisms and illustrative material. Many of the photographs are from the Gardner Collection in the Geological Museum of Harvard University. Others have been supplied by the American Museum of Natural History, the Mount Wilson Observatory, the Engineering–Economics Foundation of Boston, Professor J. H. McGregor of Columbia University, Dr. Marland P. Billings of Harvard University, Professor W. B. Scott of Princeton University, Professor Rollin T. Chamberlin of the University of Chicago, and Professor J. W. Gruner of the University of Minnesota. Permission to reproduce published photographs or drawings has very kindly been granted by the Macmillan Company, John Wiley and Sons, the American Geographical Society, Henry Holt and Company, E. P. Dutton and Company, and the University of Chicago Press.

Professor Harlan T. Stetson of Harvard University, Professor Douglas W. Johnson of Columbia University, and others have greatly aided in the preparation of the text or in the selection of illustrations. Mr. Edward A. Schmitz has prepared most of the maps and diagrams that were drawn especially for this book. My wife, Marie Porter Mather, has served most capably as edi-

torial critic, has given sound advice concerning the form and manner of presentation for the non-technical reader, and has read the printer's proof. Miss Marian L. Drisko and Mr. Randolph C. Ray have rendered careful and efficient aid in the preparation of manuscript and illustrations for the press. To all of these my hearty thanks are extended.

KIRTLEY F. MATHER

CAMBRIDGE, MASSACHUSETTS
March 28, 1928

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OLD MOTHER EARTH

CHAPTER I

Old Mother Earth

GEOLOGY is the science which studies the earth, attempting to decipher the history of this planet and its inhabitants. The geologist believes that man is child of Old Mother Earth. In classical mythology one of the most famous exploits of the great hero Hercules was his encounter with Antæus, the wrestler, son of Ge, the Earth. Whenever Hercules succeeded in forcing his opponent down upon the ground, Antæus drew strength from Mother Earth, until finally Hercules held his antagonist high in the air while he put him out of competition. Again, in the picturesque language of the literature of ancient Palestine, as recorded in the book of Genesis, the patriarchs described man as formed of the dust of the ground. To them, as to us, man was an offspring of the earth; the earth was his mother.

There was a time when the earth was believed to be the centre of the universe. Over its flat surface was arched the solid firmament of the heavens; around or above it, moved the sun, moon and stars; but modern astronomy has removed the earth very far from that position of prime importance and central splendor. We now know that it is only one of many tiny specks of matter moving swiftly through far-flung space. In very truth, the earth is merely a third-rate planet in a second-

rate system belonging to one of many assemblages of stars.

In the solar system the earth is just an average member of the family of planets which belong to the sun. Many of the other planets are larger than the earth, one of them, Jupiter, being more than 300 times as massive. Others, like Mercury, are much smaller. Except for the somewhat dubious distinction that the material of which it is composed is denser than that of any other planet, the earth has no claim, in the light of present knowledge, to superiority among the planets of the solar system, as far as its physical constitution goes. It is but a fleck of dust in comparison with the sun, for the latter is 300,000 times as large.

Even so, the sun is nothing about which one may boast in well-informed circles. It is an ordinary star, one of many such stars in the great galaxy to which it belongs. In this assemblage there are many other suns that are bigger than ours; many that are smaller; some that are hotter; some that are colder; some more slowly moving, and some that are swifter. Neither the sun nor the earth occupies a central position in the known universe.

Though the heavens on a clear and cloudless night appear to be thickly studded with stars, the fact is that the universe is characterized more by space and energy than by matter. So distant is the earth from the sun that it requires approximately eight minutes for light, travelling at a velocity of 186,000 miles per second, to

TABLE I

FACTS CONCERNING THE SOLAR SYSTEM

	Number of Moons	Average Distance from Sun; Millions of Miles	Time of Revolution about Sun	Average Speed in Orbit; Miles per Second	Density (Water = 1)	Rotation Period	Mass (Earth = 1)
Sun	..	..	..	..	1.41	24.6 days	332,000
Mercury	..	36	88 days	30	3.8	88 days	1/25
Venus	..	67	225 days	22	4.9	?	4/5
Earth	1	93	1 year	18.5	5.5	$23^h\ 56^m$	1
Mars	2	141.5	1.9 years	15	4.0	$24^h\ 37^m$	1/9
Asteroids	..	Variable	2–8 years	Variable	3.0 (?)	?	Variable, all very small
Jupiter	9	483	12 years	8	1.3	$9^h\ 50–55^m$	317
Saturn	9 and rings	886	29.5 years	6	0.7	$10^h\ 14–38^m$	95
Uranus	4	1783	84 years	4	1.3	$10^h\ 42^m$	14 2/3
Neptune	1	2794	165 years	3	1.6	(15^h ?)	17 1/6

come from the sun to us. The outermost planet in the solar system, Neptune, is so far away that four and one half hours are consumed by light on its journey thither from the sun. This gives some measure of the dimensions of the solar system. That planet, Neptune, travels at a velocity of about three miles per second in its pathway around the sun; but even at such high speed, 165 years elapse before it can complete one circuit of its orbit. Even these vast dimensions are dwarfed by the distances between the stars which form the great cluster round about us. Our ordinary notions of distances fade into insignificance, and a new unit of measurement must be used to describe their relative positions. This unit is called a light year; it is the distance traversed in one year by light travelling at the velocity of 186,000 miles per second. The star nearest to us, other than our own sun, is nearly four and one half light years away, the average distance between two neighboring stars in the stellar galaxy being eight or ten light years. The earth in space is like a tiny cork floating in the midst of the Pacific Ocean.

The astronomer is not alone in this apparent belittling of the earth as he informs us with deadly accuracy concerning the cruel facts, for the geologist adds his contribution of knowledge which emphasizes the insignificance of this planet. We have fairly good reason for believing that the family of planets now attendant upon the sun, and to which the earth belongs, is but one in a series of successive generations of planets. Before the earth

came into being as a member of the existing family, there may well have been an earlier system of planets revolving around the sun. When our earth passes out of existence, as inevitably it must some day, it may well happen that the death throes of the earth and its companions will prove to be the birth pangs of a new generation of planets, which likewise will have a brief span of existence as another trivial episode in the unending history of the stars. The inconspicuous place of the earth in space is thus matched by the insignificance of the earth's history in the endless flow of time. Instead of being a cork, lost in the immensity of a Pacific Ocean, the earth in time and space is but a speck of foam on the crest of a single wave, visible for just an instant as one of countless flecks of foam and then gone forever.

Nevertheless it is Old Mother Earth just the same, because you and I are here. From the human point of view, this place and this time have the greatest significance. As children of the earth we rightly consider this particular planet with more than passing interest, unimportant though it may be from any other point of view. Brief though its existence must be when considered in relation to the leisurely evolution of the stars, the earth in human reckoning is a very elderly mother. The history of this planet in the solar system must be measured in units of hundreds of millions of years. Just how many of those units are involved in the earth's past we cannot tell with exactness, but in all probability they will aggregate at least a billion years. Turning from

the long perspective of the past toward the future which knowledge of the past permits us to forecast, the geologist concludes that the earth will continue to be a pleasantly habitable abode for life as we know it during countless millions of years to come. We have good reason for believing that the catastrophe which eventually will overwhelm the earth and make it unfit for human habitation is an extremely remote event, hundreds of millions of years distant. That long future, stretching out beyond human measure, makes imperative the inquiry into the relation which mankind bears to the world in which he lives.

Man is a very young species of animal. A fair estimate of the average period of existence of the many species of mammals, man's nearest relatives in the animal kingdom, which "have had their day and ceased to be," is something like half a million years. The existing species of mankind, *Homo sapiens*, has been in existence only thirty or forty thousand years. There are, to be sure, extinct species of *genus homo*, of *mankind*, which go back hundreds of thousands, perhaps a million years, but that is another story. The species to which you and I belong has lived but a small fraction of the period which, by analogy with other animals, may be expected to mark its existence on the earth.

In the life history of each species of animal there appears to be a period of youth, a period of maturity, and a period of old age. The species, like the individual, is plastic, buoyant, vivacious in youth. It is then willing

to try new experiments; its ways are not fixed, its nature is not definitely and finally determined. But as the individuals pass on the torch of life from generation to generation for that particular species, there is a transition from specific youth to specific maturity. A groove is dug in the pathway of life. The ways of the species become fixed; and when it later enters the period of old age, it has become quite inflexible. "You cannot teach an old dog new tricks" is paralleled by the verdict of science that in the closing stages of the history of a species its nature is fixed beyond change. Opportunities for modification of the species are neither so numerous nor so readily grasped.

With considerable optimism we reach the conclusion that the golden age for *Homo sapiens* is in the future rather than in the past; that mankind is now in a state of youthful plasticity; that human nature is not yet definitely determined. It therefore behooves us to give ear to nature, in the hope of discovering what has determined success or failure in the past for our kin, the so-called lower animals. Knowledge of the factors which have formed habits on the long road traversed by living creatures during past geologic ages cannot fail to be of assistance in lighting the way which beckons toward the future. Information concerning the pitfalls escaped, the blind lanes detected, and the hillsides climbed, may aid in charting safe passage through the unmapped wilderness which lies before us; because narrow is the gate, and straitened the way which has led to man, and few

are those who have found it. We must therefore get well acquainted with Old Mother Earth and her moods.

Sometimes Old Mother Earth appears to be an enemy rather than a friend of man. She seems to have her angry moods, not always appearing to smile warmly and lovingly and benignly upon her offspring. When the ground is shaken by an earthquake, or tornadoes sweep across the landscape, or floods are loosed in the lower reaches of a Mississippi River, it seems at first glance as if she has forgotten that we are her children and were venting her wrath upon creatures whom she hates. But from the point of view of the geologist, such displays of force and power are not to be rated as truly destructive. In the long run, earthquakes, tornadoes, and floods are constructive forces. Were it not for them, there would to-day be no pleasantly habitable lands. Let the wear of running water, of moving winds, of sliding glaciers, of turbulent waves and currents go on unhindered through geologic time, and the result would be the disappearance of the lands. In very truth, the hills would melt away as the mist; actually, the mountains would be thrown down and cast into the sea. To-day the earth would be encircled by a world-wide ocean.

But man is a terrestrial animal. We enjoy our sea voyages, we profit by the presence of the oceans which cover three fourths of the earth's surface, but we are always glad to step foot upon terra firma. The land is our birthplace and our home. The earth is a suitable abode for man, because it has continents as well as seas.

The continents would not stand to-day above the sea floor had there not been earthquakes in the past. Mountains are upreared as beautiful displays of scenery and as custodians of great natural resources only because earthquakes and volcanic eruptions have occurred again and again. Such displays of natural force are necessary to make the earth the pleasant abode for man which we find it to be to-day.

To be sure, that does not give a very large grain of comfort to the citizens of Santa Barbara when buildings come rattling down upon their heads, or to the inhabitants of Miami when a tropical cyclone hurtles in across the ocean, or to the dwellers in Louisiana when the muddy waters of the Mississippi break through the levees and sweep across their plantations.

But it is too easy and quite unfair to cast all the blame on Old Mother Earth. Earthquakes are destructive from the human point of view chiefly because of human folly and frailty. A man alone in an open field is not likely to be injured during an earthquake. Put a crowd in that open field at the time of the earthquake, and someone will be trampled under foot in the panic which will ensue. Construct a city of flimsy inflammable buildings closely packed upon that field, and death and destruction will follow in the earthquake's train. When a man is hurt in an earthquake it is because something falls upon him, and in at least ninety-nine cases out of a hundred the something that falls has been erected by man, poised ready to fall when Old Mother Earth shakes

her shoulders and trembles a little bit in the effort to renew or to increase the altitude of the land. Again, when the Mississippi bursts the levees and inundates the bottom lands of the delta, it is largely because man has in the last few decades been building more and more levees and longer and longer dikes along the tributary rivers. Draining the swamps and confining the streams in narrow channels have hastened the flow into the main trunk stream. We have been doing all we could in the last fifty years to get the water from the rains and snows of two thirds of the area of the United States to flow into the channel of the Mississippi River just as promptly as possible. No wonder each successive flood sets a new record! There have been no changes in the climate during that time; it is not so much a matter of deforestation; it is in large part the building of dikes and levees themselves. Man is to blame.

Volcanic eruptions, earthquakes, and tornadoes are not respecters of persons. The moral qualities or religious beliefs of the inhabitants of a community have no influence whatsoever upon the forces pent in the interior of the earth or upon the movements of the atmosphere. The rain falls alike upon the just and the unjust. The iniquities of the "Gold Coast" had nothing to do with the destruction of San Francisco in 1906; the damage suffered at Miami in 1926 cannot be attributed to the playing of golf or the racing of horses on Sunday. Prayers, profanity, or burnt offerings have no more effect upon the wind, the tide, the volcano, or the earthquake than they have upon an eclipse of the sun. The laws

which control such natural forces as these are not subject to our puny wills. When the earth gets ready to tremble at any particular spot, an earthquake will occur despite anything that we have done or can do. Trusting to Providence or trusting to luck that I will not be harmed are two of our commonest iniquities.

Inanimate nature is wholly neutral toward man; it is neither for him nor against him. The laws of nature which order the sun, moon, and stars n their courses, which cause the tides to ebb and flow, which determine the time and place of tornadoes or earthquakes, operate in a wholly mechanical way. These laws have been grinding on throughout geologic time, long before man appeared upon the earth, and presumably they will continue to operate long after he is gone. Experience indicates unmistakably the fact that ignorance of the law excuses no man. Lack of knowledge of the relation between the anopheles mosquito and the germs of malaria does not protect the ignorant from the ravages of that disease.

But Old Mother Earth is a very wise mother. Not only does she challenge man to solve the problems which she sets for him, she also whispers suggestions as to the method of solution. She is always ready to reveal her choicest secrets to the patient and humble investigator. Knowledge thus gained has made man powerful. The last half century especially has witnessed much progress in the task of "subduing the earth." The facts and theories of geology are not only interesting, they are of vital importance to the welfare of mankind.

CHAPTER II

How the World was Made

"WHENCE came this world and whether formed by hand Divine or no?" is a question which has interested man ever since he began to think about himself and his surroundings. All rational answers to this question have involved the development of the orderly solar system from a disorganized and chaotic state. Even in the primitive account of creation recorded in the first chapter of Genesis, one finds the idea that "in the beginning . . . the earth was without form, and void." Then, in orderly sequence and through natural processes the world assumed its present form and produced its present population.

Discovering "how the world was made" involves a survey of the vestiges of creation, found in the form, position, and movement of the several bodies in the solar system. When man discovered that each planet revolves about the sun in an elliptical orbit, that all travel in the same direction, and that the velocities of the several planets increase regularly from outermost to innermost, it was at once, and wisely, concluded that the solar system must be a result, not of chance or accident, but of definite laws, operating to bring order out of chaos.

A French astronomer, Laplace, in the closing decades of the eighteenth century, reached the conclusion that

the solar system must have started its history as a nebula, the astronomer's term for a great mass of hazy, disorganized material. Laplace's nebula was a huge ball of extremely hot gas, rotating at high velocity upon its own axis. As it spun in space, the nebula slowly cooled and condensed. Shrinking thus to smaller dimensions, it necessarily rotated more rapidly and became greatly flattened at its poles and tremendously bulged at its equator. With increased speed of rotation, centrifugal force increased in opposition to gravity. Centrifugal force is the inertia which causes water to remain in a half-filled bucket even though the bucket is upside down as the boy swings it overhead. It is the force which causes the fragments of a wheel to fly off into space if the wheel is spun too rapidly. This force would be concentrated in the equatorial bulge of the spinning gaseous nebula. When rotation had become rapid enough to make centrifugal force equal to the force of gravity, a ring of gas would therefore be dropped from the equator of the shrinking nebula. Laplace believed that nine such rings were formed as the nebula condensed from its earlier huge dimensions toward its present condition. According to this theory, the first ring was left behind at the place now occupied by the orbit of Neptune, the outermost planet. The seventh ring contained the matter now in the earth and moon, and was dropped from the nebula at the position now occupied by the orbit of the earth. The last ring became the innermost planet, Mercury, and the residue of the original nebula is now

the sun. Nine rings were required, although the solar system contains only eight planets, because it was believed that the fifth ring formed the group of small planetary bodies called asteroids, which are located between the orbits of Mars and Jupiter. Each ring except the fifth one became a single ball of gas, spinning on its own axis as it revolved around the sun. Each such ball of gas would spin with forward rotation, as do all the planets whose rotation is known, because the outside of the ring would necessarily move more rapidly than the inside.

As the ball of gas, later to form the earth and moon, thus revolved around the sun and rotated upon its own axis, it likewise cooled and condensed. Its rotational velocity increased just as that of the huge parent nebula had done. Finally a ring of gas was dropped from its equator and occupied the present position of the orbit of the moon. As the earth continued to radiate heat, the gas of which it was originally composed condensed into a very hot liquid and finally its surface became solid. In the meantime, the moon ring had become a ball and had completely solidified. Because this theory seemed to explain satisfactorily all known facts concerning the motions of the planets and their moons within the solar system, it was looked upon with favor by the great majority of scientists during the nineteenth century.

This so-called nebular theory implies that the solar system has steadily lost energy as its component parts radiated heat into space. It suggests that the earth is to-

day a liquid sphere, the outer surface of which has frozen into the solid crust upon which we live. This, of course, was in harmony with the orthodox theological view that hell is a place of tremendous heat, situated below the surface of the earth. The theory also implies that at no distant date in the future the continually cooling earth will become, like the moon, so cold that it can no longer serve as an abode for life.

But in the last few decades we have learned a great many more facts about the solar system, and we have come to a more accurate understanding of the operation of natural laws. The total amount of motion, the *momentum*, of the solar system is now known. A ball of gas, containing all the matter of the solar system and having all its motion, would not rotate fast enough to cause centrifugal force to equal gravity, and thus permit a ring to be dropped from its bulging equator, until it had shrunk to so small a size that the first ring would have been far inside the orbit of Mercury, instead of in its required position, where now is the orbit of Neptune. Unfortunately for the nebular theory, the sun is spinning very slowly upon its axis. At the equator of the sun, the rotational velocity is only about one and a third miles per second, whereas Mercury travels twenty-nine miles per second in its orbit around the sun. Contraction of the Laplacian nebula to the present radius of the sun after the Mercury ring had been dropped should have given the sun an equatorial velocity of 270 miles per second. This is a death-blow to the Laplacian theory,

and merely illustrates the many discrepancies between the theory and the facts now known concerning the sun and its planetary family. Many of these discrepancies may be summarized in the statement that all the planets and moons together possess less than one seventh of one per cent of the entire mass of the system, whereas 98 per cent of the momentum of the system pertains to the planets and only two per cent to the huge central sun. To distribute energy in this unbalanced way throughout the solar system requires the interference of some outside agency. No simple process of condensation of a cooling, gaseous nebula, organized by centrifugal action, could ever account for the solar system as it is now known. The Laplacian nebular theory must be abandoned.

Working upon these problems nearly thirty-five years ago, Dr. T. C. Chamberlin, geologist, and Dr. F. R. Moulton, astronomer, began to devise an alternative theory, which is known to science as the Planetesimal Theory of Earth Origin. They assumed that long ago our sun passed in fairly close proximity to another similar sun, one of the stars in the group of stars surrounding us. If the disturbing star approached our sun at a distance between one and five times the present diameter of the orbit of the outermost planet, tidal strains would partially disrupt each body and completely destroy whatever planetary attendants either sun may have had. About one per cent of the mass of our ancestral sun is believed to have been ejected in two great bolts of matter shot

Courtesy of Mount Wilson Observatory

FIGURE 2. This spiral nebula in the "Big Dipper" was photographed with the 60-inch reflector at Mount Wilson Observatory in California on March 10 and 11, 1910. It is quite invisible to the naked eye, and an exposure of seven and a half hours was required to show its more faintly luminous portions; during that time the telescope was steadily turned so as to counteract the rotation of the earth and keep its line of sight directed toward the centre of the nebula.

out from its equatorial belt. One bolt was projected toward the disturbing star; the other bolt was thrown outward in an exactly opposite direction.

The passage of the disturbing star and the rotation of our ancestral sun combined to throw much of the ejected matter into the form of a spiral nebula. Some of this matter fell back into the sun, and in so doing changed its rotation, giving it the extremely low rotational velocity which it now has. Some of the ejected material escaped into space, and may now be represented by certain of the comets. Much of it, however, assumed elliptical orbits around the sun.

The ejected material may have been in part gas and in part liquid, but it is suggested that most of it quickly assumed a solid state. Scattered at varying distances along the arms of this particular spiral nebula there must have been local concentrations of matter in the form of nuclei. These served as centres of aggregation, around which each of the planets grew, as the separate particles of the hazy nebula were added to each nucleus by accretion.

The planetesimal theory suggests that the earth nucleus at the start contained perhaps one tenth the present mass of the earth and that there was another smaller nucleus, the moon nucleus, so close to the earth nucleus that from the first it was held under control as a satellite. Each nucleus increased in mass, as small particles, the planetesimals, were gathered in whenever the orbits overlapped each other. This process of plane-

tary growth is now almost ended; only a few planetesimals still remain within the space occupied by the solar system. These are occasionally apparent as meteorites, or "shooting stars."

A mathematical analysis of the conditions under which the planetary nuclei would grow by accretion of planetesimals explains admirably the peculiarities of the solar system. Forward rotation would be the rule, but an occasional exception might occur. The planets receiving the greatest number of impacts from planetesimals would have the most nearly circular orbits; and the largest of our planets to-day have much less eccentric orbits than do the smaller ones. The revolutional velocity of the moons need have no definite relation to the rotational velocity of the planets controlling them. The outer planets would be composed of less dense material than the inner ones.

Under this theory the earth has been essentially solid since its earliest infancy. Its history has been characterized by growth, rather than by decay; by the addition of energy, rather than by its loss. At first the earth had little or no atmosphere; but it began to hold the several atmospheric gases as soon as it grew so big that its gravity was sufficient to overcome their molecular velocity. To-day, for example, the earth's gravity is sufficient to retain all except the lightest gases, hydrogen and helium. The atmosphere would have been sufficiently dense to hold water vapor when the earth was approximately one half its present mass, at which time

FIGURE 3. Professor T. C. Chamberlin is best known for his theory of the origin of the solar system from a planetesimal nebula.

the first rains fell and the first seas began to form. At about that same stage the earth would have been suitable as an abode for life.

Within the last five years an important modification of the planetesimal theory has been proposed by J. H. Jeans and Harold Jeffreys, eminent British physicists. They suggest that at the time of dynamic encounter of our sun with the neighboring star, the sun, instead of having dimensions like those which it now possesses, was very much more expanded and had a diameter about as great as the present diameter of the orbit of the outermost planet, Neptune. Tidal disruption under such conditions would be concentrated on the nearer sides only, the effect of this encounter being the ejection of a stream of gas from the surface of the sun toward the passing star. This ejected stream of matter would cool very rapidly by radiation and promptly condense into a liquid. Such a jet or filament would be unstable and, as it condensed, would break into separate bodies, the planets. Owing to the orbital velocity imparted by the passing star, these planets would not fall back into the sun but would describe elliptical orbits passing near it. As this took place, the sun would have an effect upon the passing planets similar to that of the star upon the sun, and satellites would be drawn out from them.

In the Jeans-Jeffreys Tidal Theory the earth must have passed through a liquid stage, passing gradually into the solid state by cooling from the surface. To the geologist this is the significant difference between this

theory and the planetesimal hypothesis of which it is a modification. At present, it is quite debatable whether the few facts known about the interior of the earth are better explained on the supposition that the earth was formerly quite completely liquefied, or that it has been essentially solid throughout its entire history. With increasing ability to interpret earthquake records and with more detailed knowledge of the distribution of materials just beneath the earth's surface, it is probable that in a few years geologists will be able to pass judgment upon the matter.

Be that as it may, the accepted ideas concerning the origin of the earth and its fellows in the solar system are sufficiently stimulating to be worthy of careful consideration. To modern science, the making of the world is not a process of creation as that term is frequently used. The planetesimal and tidal theories do not consider for a moment the possibility of making something out of nothing. The whole concept of dynamic encounter of two stars implies merely the reorganization of previously existing matter and energy into new arrangements, and the entire history of the solar system is but one brief chapter in the endless flow of stellar evolution. For the scientist there is no beginning and no ending. Scientific theories do not deal with ultimate causes or effects; they consider only the proximate causes and the immediate effects.

Dynamic encounter between two stars must occur with relative frequency in each great cluster or galaxy of

Courtesy of Mount Wilson Observatory

FIGURE 4. Great fountains of gas are constantly playing outward from the envelope of the sun, whose body is concealed behind the black disc at the right of this photograph taken at Mount Wilson, California. The longest prominence near the top of the picture is 80,000 miles high.

stars — in each of the "island universes" which dot the far reaches of limitless space. Perhaps every star undergoes such a catastrophe on an average of once in every five or ten billion years. When such an episode occurs, it is a rejuvenating event. Our sun, for example, had been growing old. The family of planets, which it may well have had in its train, had long been in existence; they had had their day and now they ceased to be. There was a new deal in the great game, a new distribution of matter and of energy. The sun was returned to the youthful stage in which it either was surrounded by a spiral nebula or possessed a filament of condensing gas. The history of the existing solar system was thus begun. As in the past, so in the future; for a few billion years the earth and its planetary companions may enjoy their "place in the sun." Then another episode of close approach to another star will destroy the existing system and start a new cycle of solar evolution.

CHAPTER III

The Origin of Life

THE most fascinating subject in the world is life and its meaning. Not the least interesting phase of that subject pertains to the way in which living creatures first appeared upon the earth. The geologist is frequently requested to relate what is known concerning the origin of life upon this planet.

The record of the rocks reveals a marvellous story of the succession of living creatures which have populated the globe during geologic time. Petrified bones, fossilized shells, hardened footprints, carbonized leaves, and many other indications of animals and plants occur in the rocks at many places on the surface of the earth. Some fossils were entombed in the sands washed together along the sea-shore, some represent animals killed and buried in volcanic ash, others are the plants of a marsh buried by wind-blown sand or river-borne mud, and still others are of animals which were caught in bogs or quicksands along the banks of sluggish streams. As a rule, the fossils in any bed of rock indicate the kinds of animals or plants which lived at or near that place at the time the enclosing rock was being formed. Over a large part of the earth's surface the fossil-bearing beds of sandstone, shale, and limestone appear as flat or gently inclined layers. The beds, where not broken or over-turned by

FIGURE 5. Looking down into the Grand Canyon of the Colorado River in Arizona, one sees a thick series of undisturbed sedimentary rocks resting upon the ancient crystalline complex of the inner gorge. The sequence of the beds is obviously indicated by their position, one above the other.

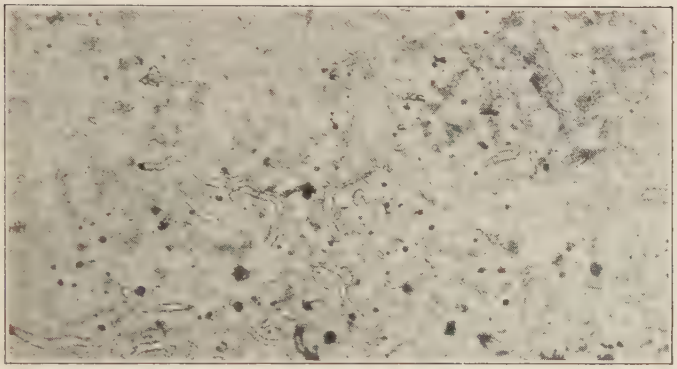
mountain-making disturbances, are to-day in the order in which they were deposited, the oldest at the bottom, the youngest at the top of the series. Knowing thus the succession of the rocks, we are able to discover the sequence of life in past ages.

The record indicates unmistakably that progressively more complex and more modern types of animals and plants have lived upon the earth in successive geologic periods. There was a time, for example, when no animals with backbones, but only the several branches of invertebrate animals, were represented in the record. Then, in succession, the fishes, the reptiles, and the mammals made their first appearance among the assemblages of fossils. Working backward through the record toward its earliest chapter, the many diverse strains of living creatures converge toward each other; differences which now separate one kind of animal from another disappear; complexly organized forms are seen to have been preceded by simple ancestral types. The conclusion is inescapable that the first living creatures upon the earth must have been very lowly one-celled individuals, primordial plant-animals, at least as simple and generalized as the least complicated of existing forms of life.

But the record fails absolutely when traced backward that far. The oldest known rocks are entirely devoid of fossils; the oldest known fossils are the remains of creatures already considerably advanced beyond that initial stage. There is no known record of the beginning of life upon the earth, nor is there the least hope that one

will ever be found. Unhampered by facts, we are left free to speculate to our heart's content. But that does not mean that we should indulge in a lot of indiscriminate guessing. Once more the vestiges of creation, when clearly discerned and rightly understood, may lead to rather definite knowledge concerning how things came to be as they are. Living matter exists in definite ordered arrangements, rather than in a diffuse, unorganized, or formless state. The orderly scheme must be a result of orderly processes; the causes may be deduced from the effects. By their fruits may the laws of nature be known.

The living creatures known to us are beyond doubt the offspring of Old Mother Earth. Adaptation to the earthly environment is so complete that they cannot be looked upon as immigrants from some other world. Science long ago branded as idle and foolish speculation the fanciful theory that living beings, seeds, eggs, or spores were transferred through interplanetary space from some other heavenly body, to propagate life upon the earth. Life, as we know it, must surely have originated here upon this planet, in the midst of the environment to which it is so well suited. The principle of evolution implies not only that all living creatures have come into existence through descent with modification from previously existing animals or plants, but that the primordial plant-animal which formed the first link in the chain of life was also a result of the orderly transformation of previously existing matter and energy. The previously existing matter must have been inorganic min-



Microphotograph by John W. Gruner

FIGURE 6. The oldest known fossils are microscopic algae, very simple types of vegetation, found in the early Proterozoic rocks of the Lake Superior Region. The rock was cut in a slice so thin as to be transparent, and the algal filaments are shown here as they appear under a high-power microscope, enlarged 190 times their natural size.

eral matter. The living must have been produced from the non-living. Toward this conclusion the accepted fundamental principles of modern science lead inevitably.

Living beings are characterized by unusual forms of energy and by peculiarly complex matter. The material basis of life is called protoplasm, and the unit of protoplasm is the cell. Every individual animal and plant starts its life as a single energized cell; differences between adult individuals of different species are found more in the different ways the many cells are associated in the single individual, than in differences between individual cells. Protoplasm is an apparatus for transforming energy, and life is the result of the reaction of energy and protoplasm. The origin of life, therefore, involved the construction of the material substance, protoplasm, its structural organization into a cell, and its dynamic organization so that it displayed what we call "vital energy."

Complex compounds, such as those found in living tissues, can exist only within a very narrow range of temperatures. At extremely high temperatures, as in the interior of the sun, only those forms of matter which we term elements can remain in equilibrium. More than likely, many of the elements at such temperatures are decomposing, as radium is to-day in the comparatively cool environment of the earth's surface. Lower in the temperature scale, elements unite into more or less complex compounds, and these may remain in stable equilibrium. Under the Planetesimal Theory of Earth Origin,

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the density of the atmospheric envelope surrounding the solid and growing earth would largely determine whether or not living compounds could be formed under conditions of stability. This theory implies that surface temperatures upon the earth have, from a very early stage, been determined, not by the internal heat of the earth, but by the energy received and retained from the sun. If, at the beginning of its independent history, the earth was too small to hold any of the atmospheric gases, a considerable interval must have elapsed before life could appear. During that interval the growing earth gradually acquired an atmosphere as its gravity increased with increasing mass. When it had a mass one third or one half as great as it possesses at the present time, it was big enough to hold an atmosphere comparable to that now found on high mountains. So far as we can tell, all the conditions requisite for life were then present at the earth's surface.

Nature is not in the habit of overlooking opportunities, and it is likely that life appeared upon the earth shortly after the earth became a suitable abode for living creatures. If so, the surface upon which the first living organisms dwelt is to-day buried hundreds of miles deep in the interior of the earth, because a considerable proportion of the earth's growth by the accretion of planetesimals took place subsequently. Under the Jeans-Jeffreys theory, a modification of the planetesimal hypothesis, which involves the condensation of the infant earth from gas to liquid and then to a solid, the surface temperatures

were determined for a long time by the internal heat of the earth. Not until this heat was radiated out into space so that a thick solid crust could form around the liquid sphere, did temperatures approximate those essential for life. No vestige of such an original crust has ever been found, nor is it likely that it now appears at the earth's surface anywhere. On the basis of either theory of earth origin, the presumption is strong that life was in existence upon the earth before the oldest known rocks were formed.

To-day there is a conspicuous gulf between the inorganic substances and the living beings known to man. The non-living is not now being transformed into the living, except through the agency of animals and plants themselves, as in the assimilation of food. Spontaneous generation does not occur in nature. Although many inorganic substances imitate in certain important particulars the characteristics of living cells, no chemist has yet been able to construct from them a cell of protoplasm which could grow and reproduce itself. Life has never been artificially produced in the laboratory, although the attempt has frequently been made.

Nevertheless, it does not follow that the gulf between the non-living crystal and the living cell was never bridged. On the contrary, the only safe grounds, within which speculation concerning the origin of life is justified, are those which imply that the material substances from which living cells were first constructed were previously present among the rocks and minerals of the earth. The

chemical elements essential in living protoplasm are among the commonest of all the elements in the universe. Carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulphur are quite generally distributed in the crust of the earth or in its atmosphere. All the necessary material ingredients for protoplasm were certainly present in the outer shell of the juvenile earth. The meteorites which have fallen to the earth's surface in the last few years contain unstable and highly complex carbides, nitrides, phosphides, and so forth. Presumably these are samples of the materials which under either view of earth origin must have been added to the juvenile earth while it was assuming its present form and state. In the earth's atmosphere many of these substances spontaneously decompose, forming new compounds and affording limitless opportunity for chemical change and recombination.

There is a widespread idea that life originated in the sea. Many of the simplest creatures known to man now dwell there; the oldest known fossils are the remains of marine creatures. Nevertheless, the sea does not appear to be a favorable location for the chemical synthesis of protoplasmic compounds. To construct protoplasm, concentration rather than diffusion is necessary. A long series of chemical reactions is involved. Dilution would hinder rather than favor the successive steps. The moist ground is a more likely place for the origin of life than the sea with its shifting currents and tendency toward dilution. In that far-off period of earth history before life appeared upon this planet, the lands must

have been covered with loose pulverized débris, the result either of planetesimal infall or of volcanic eruptions, or both. The open spaces at variable distances below the actual surface of the ground must have been filled with water from the primordial rainfalls. Except during the rains, the pores in the ground close to the surface were comparatively dry. Somewhere between the surface and the saturated zone a score of feet below, any desired relationship of water, air, and mineral matter could have been found. Slow circulation of the water percolating through the ground would provide a means of bringing various solutions together, and would tend toward concentration of those solutions in definite places. Here the long, slow process of chemical synthesis, constructing the chain which led eventually to the first protoplasm, is believed to have taken place. Beyond doubt there were numerous errors in the many trials attempted at different times and places. But opportunity was practically limitless both in time and space. If the needed minerals were absent at a critical point in the synthetic process in one place, somewhere else the proper sequence might be obtained. If at one locality an unfortunate episode of volcanic activity, crustal movement, or planetesimal infall, destroyed the delicate balance between the complex hydro-carbon compounds and their surroundings, somewhere else at some other time there would be no such disastrous circumstance.

It is noteworthy that many of the complex hydrocarbons occurring in nature, or formed in the laboratory without the assistance of vital processes, and therefore

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of inorganic origin, exist in what the chemist calls the colloidal state. Colloids are jelly-like substances, neither solid nor liquid. Frequently they possess the physical form characteristic of protoplasm. More than likely, the suggested chemical synthesis of the organic from the inorganic was favored by the presence of colloidal hydro-carbons in the pores between the grains of the pulverized outer shell of the primitive earth. It is possible that the walls bounding these tiny spaces in the soil anticipated the development of cell walls enclosing the protoplasm of the primitive uni-cellular plant-animal.

But this is only a part of the story. Life is something more than matter. Living creatures are characterized by vital energy — something about which we really know very little, but something which is absolutely indispensable to every organism. Obviously the material constituents of life were under the sway of geologic factors. Did those same factors also determine the energy content of the ancestral cell? Abundant sources of energy of various kinds were doubtless present at and near the surface of the growing earth. Solar radiance, electrical vibrations, radioactive compounds, chemical reactions, all of these and perhaps other sources of energy were available. It is conceivable that the synthesis of vital energy in the spiritual realm, if I may use that term in a very broad sense, paralleled the synthesis of protoplasmic substance in the material realm. Here the geologic factors are so obscure that it is hardly worth while to attempt any speculation.

Chamberlin closes his volume on the origin of the earth with the following thought-provoking sentence: "It is our personal view that what we conveniently regard as merely material is at the same time spiritual, that what we try to reduce to the mechanistic is at the same time volitional; but whether this be so or not, the emergence of what we call the living from the inorganic, and the emergence of what we call the psychic from the physiologic, were at once the transcendent and the transcendental features of the earth's evolution." With this conclusion, many geologists are in hearty accord. May it not be that life as we know it is but one manifestation of the mysterious spiritual powers which permeate the universe? The geologic factors assembled in the primitive earth provided an environment within which the spiritual could manifest itself in the material. The form which it should assume may have been largely determined by that environment. At the very genesis of organic evolution the physical environment presented an opportunity and suggested a method for its utilization. The primitive cell was the result.

From that first living creature there have descended the many varied forms of animal and plant life which comprise the diversified population of the earth to-day. Among its remote offspring is man, a complex organism whose body is constructed of exactly the same sort of ingredients as the protoplasm of which the cell was composed. Thus in very truth is man formed of the dust of the ground.

CHAPTER IV

The Path of Life

THE materials of the earth's crust owe their present form and distribution to the operation in the past of forces which are at work to-day. Ever since the waters of the sea were gathered in the ocean basins, the waves and currents have been busily at work, pounding against cliffs, sweeping away headlands, distributing pebbles, sand, and mud along the shores. The oldest rocks now known, in Ontario and Quebec, indicate that rivers were at work eroding the lands, volcanoes were in eruption, and winds were blowing in that distant geologic period just as they are to-day. Sediment carried by rivers to the deltas at their mouths, blown out to sea by off-shore breezes, or shifted from place to place by ocean currents, is compacted or cemented into solid rock. Entombed in the rocky strata are the fossil remains of animals and plants that lived somewhere near the place where found, during the time that the sediments were accumulating.

These relics of ancient life are the torn and tattered pages of Old Mother Earth's Outline of History. The fragments of the record have by this time been sufficiently recovered and interpreted to reveal much of the story of life-development. We may stand upon the reviewing platform and watch the procession of living creatures as it moves along the path of life. It comes out of the black-

TABLE II

THE GEOLOGIC TIME TABLE

Era	Period	Physical Events	Life Development
	Quaternary		
	Recent	"Post-glacial time"	Man comes to N. America.
	Pleistocene	"The Great Ice Age"	Advent of mankind.
Cenozoic	Tertiary		
(Age of	Pliocene		One-toed horse.
Mammals)	Miocene	Great volcanic activity in Western States	Three-toed "horse."
	Oligocene		
	Eocene		First placental mammals.
		Folding of Rocky Mts.	Extinction of dinosaurs.
	Cretaceous		Climax of reptiles on land, in air and in sea.
Mesozoic			
(Age of	Comanchean		First flowering plants.
Reptiles)	Jurassic	Birth of Sierra Nevada	First birds.
	Triassic	Volcanic eruptions in Connecticut Valley	First dinosaurs.
	Carboniferous		
	Permian	Folding of Appalachian Mts.	
	Pennsylvanian	Extensive coal-forming swamps	First reptiles.
Paleozoic	Mississippian		First land vertebrates.
	Devonian		"Age of fishes."
	Silurian		First ferns and evergreens.
	Ordovician		First fishes.
	Cambrian		First abundant fossils.
	Keweenawan		
	Huronian	Oldest known glaciation	Scanty record of very lowly plants and primitive animals.
Proterozoic	Algoman		
	Sudburian		
	Laurentian		
Archeozoic	Grenville		
	Keewatin	Oldest known rocks	

ness before the dawn of the first geologic record; then rank upon rank, and row upon row, it moves forward into the fuller knowledge of more recent time. To mark the outstanding events in the evolution of the earth and its inhabitants, the geologist in imagination erects monuments along the pathway. For example, one of these milestones was the construction of the lofty Laurentian Mountains in central Ontario and Quebec, a mountain range long since worn down and cast into the sea. It marks the close of the first of the five great eras into which geologic time is customarily divided. The second era was closed by a similar crumpling and uplifting of the earth's crust to make another long-vanished mountain system in the general vicinity of Lake Superior. The milestone at the close of the third era is the folding of the Appalachian Mountains; while at the end of the fourth era, the Rocky Mountains were formed.

Records of the life which was in existence during the first two of these long eras of earth-history are very scanty. Remains of microscopic, blue-green, water-dwelling plants, known as algae, evidences of bacterial life, fossil sponges, worm burrows, and possibly the trails of mollusks, have been observed among the ancient rocks of that time. The variety of living creatures thus indicated as present at the dawn of the geologic record is impressive, but little is known concerning them.

At the beginning of the third era, the record abruptly expands. The sedimentary rocks of that and subsequent times are generally rich in fossils. The names of the eras

are themselves suggestive of the successive types of life. For example, the era which was closed by the crumpling of the Appalachian Mountains is known as the Paleozoic, the era of ancient life. The next era is the Mesozoic, the era of medieval life; while the time since the birth of the Rocky Mountains is the Cenozoic Era, the era of modern or recent life.

At the start of the Paleozoic Era, there seem to have been no vertebrates or seed-bearing plants in existence. The animals were all among the lower orders; none were possessed of a backbone or spinal column. Then, in regular order, the fishes, the amphibians, and the reptiles made their appearance in the record of Paleozoic time. By the end of that era, the ferns and evergreens had developed on the lands. During the Mesozoic Era, the reptiles deployed into many curious strains, and the birds, as well as very primitive mammals, arrived. It was during that era, also, that the flowering plants and deciduous trees are first recorded. In the Cenozoic Era the higher types of mammals, including the horse, cow, dog, cat, whale, ape, and man, make their first appearance in the procession.

Not only do progressively more complex and intelligent creatures appear as the procession of life passes the successive milestones along the pathway, but within such groups as the crustaceans or the mollusks, there is noteworthy improvement. The Paleozoic Era witnessed what seems to have been the greatest progress and most significant achievements of marine invertebrates. Dy-

nasties like the trilobites reached their climax, and declined almost or quite to disappearance. Organic mechanisms peculiarly devised for efficient locomotion were perfected by a vast multitude of diverse creatures. Sense organs of great usefulness were consummated by the representatives of numerous invertebrate orders. Protective devices of shell covering or other structures reached a superiority which has never been excelled. At the close of the era, the assemblage of marine invertebrates was far superior in every way to the ancestral types which had embarked upon the seas at its opening. Were there factors in the Paleozoic environment which could have been responsible for that remarkable progress?

One of the mechanisms which has caused evolution to be, not merely *change*, but actually *progress*, seems to be inherent in the environment provided by Old Mother Earth. During those earlier stages in earth-history the interior of North America was inundated time and again by great shallow seas or embayments, like Hudson Bay at the present time, which stretched from the St. Lawrence region to flood the lands now forming New York, Pennsylvania, and adjacent states. Other embayments came in from the Gulf of Mexico and reached as far north as Illinois or Minnesota. Still others spread down across the Northwest Territories of Canada, flooding what is now the McKenzie Valley and reaching as far south as Missouri or Oklahoma. Following each advance, the embayments withdrew from the interior.

FIGURE 7. In this sketch Professor Williston shows the evergreens, giant "horsetails" and fern trees which characterized the late Paleozoic landscapes. In the foreground are two heavy-skulled amphibians, ancestral to the early reptiles, and in the water is a primitive reptile. The dragon fly has a wing spread of about 25 inches!

From S. W. Williston, Water Reptiles of the Past and Present, with permission of the University of Chicago Press.

With each advance of the sea upon the land, the shallow seas were trebled or quadrupled in extent, whereas during times of continental uplift they were reduced to a tenth of their former area. Imagine the plight of those animals whose habitat was limited to the shallow water, who could neither get out upon the land nor flee to the deep ocean! When the seas were advancing and the area available for them was expanding, there was plenty of room for every individual, an abundance of light and food and air for all. Under such conditions the inhabitants of those seas were free to try all sorts of experiments. Almost any variation in body structure would prove satisfactory, because no severe tests were being applied.

But invariably the expansion of the seas was followed by withdrawal, which necessarily involved the close crowding of the multitude of its inhabitants into harbors of refuge at the very borders of the continents. Expansional evolution was followed by restrictional evolution. Times were severe; no longer was there luxury and ease. In those times of adversity and hardship many individuals proved unfit. Those not able to survive the new conditions of time and place were blotted out of existence. Those that did survive were, of course, the ones to carry forward the thread of life; and when the next wave of advancing seas came along, they gave rise to the expanding groups which populated the enlarging area of those seas. The rhythmic flow from expansional to restrictional evolution and back again seems to be an important phase in the process of evolution.

Moreover, as these seas withdrew from the interior of the continents each embayment was separated from the others. Provincialism was the rule. In each harbor of refuge there were a few individuals who could be considered as the champions of that particular province. Later, when the seas advanced toward the interior, they frequently united to form seaways across the continent. Thus during certain geologic periods the embayment from the St. Lawrence region coalesced with the embayment from the Gulf of Mexico, and the waters of the Arctic, flooding in from the northwest, mingled with these other waters in the interior of North America. Thus there was an opportunity for a world championship competition. The winners in the various provincial contests were pitted against each other in the world's sweepstakes. Provincialism gave place to cosmopolitanism. Out of the several regional faunas one continental assemblage would survive, and it in turn would later be divided into local units when the seas once more retreated.

Obviously, the rhythm of evolution on the land was just the opposite of that taking place in the sea. For example, very early in the Cenozoic Era some of the primitive mammals made their way into South America and then were isolated upon that continent by the breaking down of the land bridge across which they had journeyed. It just happened that among these invaders into South America there were no members of the cat family. There were, however, many hoofed, herbivor-

FIGURE 8. The single-toed proterothere roamed the plains of South America before the horse had progressed in North America to the one-toed stage. The resemblances between the two types of hoofed herbivores are due not to close relationship but to parallel responses to similar environments.

Drawing by Charles R. Knight. From Scott: Land Mammals in the Western Hemisphere. Copyright, 1913, by The Macmillan Company. Reproduced by permission.

ous, placental mammals, as well as marsupial mammals. Placental mammals are those whose young are born in a rather advanced state of growth after weeks or months of nourishment within the body of the female parent. Marsupial mammals are those, like the opossum and the kangaroo, whose young are born in a very immature condition and are carried for weeks in a pouch on the abdomen of the mother before they are strong enough to live independently. Some of the marsupials in South America played the rôle of the placental cats and closely imitated the tiger in their body structure and habits. For about two and a half geologic periods South America was isolated from North America. During that time one of the five-toed, hoofed herbivores developed into a single-toed, hoofed mammal, which lived in South America before the horse family in North America and Asia had progressed from the five-toed, through the three-toed, to the one-toed stage. The first single-hoofed, herbivorous mammal was not the horse, but was this South American creature.

When, later, the land connection between North and South America was once more restored, the South American animals migrated northward, and the North American animals southward. The competition was short and severe. The cat-like marsupials of South America were blotted out of existence, and the one-toed, hoofed mammals of South America failed, but North American horses overran the southern continent, and the tigers and other true cats from North America completed its domination.

Of the South American mammals only two have made good in North America: the armadillo of Texas, and the sloth of Central America. All the rest failed to make any headway in the northern continent.

With such illustrations in mind, it is obvious that changes in the geography of the earth have played an important directing part in the evolution of life upon its surface. During all the hazards and vicissitudes along the changing pathway, the deploying threads of life have never been completely severed. From the introduction of life upon the earth, or at least from the earliest record onward to the present moment, the pulse of life has continued, now fast, now slow; but always beating, never stopped. The environment provided by Old Mother Earth has been such that life could carry forward without interruption its changing existence here.

So far as the geologist can tell, at each step in life-development the tests were applied and the changes were accomplished without any knowledge of future tests or needs. Certain modifications in body form, which were of great advantage for the moment to certain creatures, later proved a serious handicap to their remote offspring. Sometimes we get the idea that life has moved in predetermined lines, that a particular strain of living creatures saw a distant goal and then marched steadfastly toward it. The record does not bear out that inference.

For example, there is a little verse in the geologist's anthology, which describes the ancestral type of horse, Eohippus, the "dawn horse":

FIGURE 9. The ground sloth and the glyptodon (at the right) are typical representatives of the strange group of mammals, now for the most part extinct, which evolved in South America during that portion of the "Age of Mammals" when that continent was isolated from other lands.

Drawing by Charles R. Knight. From Scott: Land Mammals in the Western Hemisphere. Copyright, 1913, by The Macmillan Company. Reproduced by permission.

Little Eohippus was no bigger than a fox,
And on four toes he scampered over Tertiary rocks;
But, said little Eohippus, "I am going to be a horse,
And on my middle finger nails, I'll run my earthly course."

The poet was obviously using a lot of poetic license. The truth of the matter is that the offspring of little Eohippus in successive geologic epochs did get up on their toes and finally ran upon the hoof, the terminal protective device of the middle toe; but Eohippus could have had no vision of his splendid equine descendant, the horse of to-day. Every change that occurred in the body structure of Eohippus and his offspring was a response to the local conditions of the time and place in which each individual lived. Each successive generation of horse-like creatures had all it could do each day to get away from some sabre-toothed cat, or to find a sufficient supply of nutritious grass or other herbage. Their thoughts were not cast far in the future. "Sufficient unto the day was the evil thereof" for little Eohippus. And that, I think, was the story of each successive step along the path of life. Progress resulted when each individual did the best it could in the conditions of time and place in which it lived, without much regard for the fate of remote offspring who might live geologic ages hence.

Again, sometimes we get the idea that the environment which Mother Earth has provided is one which tends to select on the basis of strength or fighting ability. We have heard so much about the survival of the fittest

in the struggle for existence that the emphasis seems to be placed upon combat and strife. There is a tendency to think that survival is measured in terms of ability to kill; that it is the strength of talon and of claw that determines survival value. To some, "fit" seems to be the past tense of the verb "fight." But the record indicates that survival values were measured in various ways at different epochs in the history of life.

There is, for example, the thrilling story of the rise and fall of the dinosaurs and their kin. The remarkable motion picture, "The Lost World," gives a very splendid portrayal of the battle of the dinosaurs, cold-blooded, small-brained, huge-bodied brutes, who placed their confidence in armament and bulk. This motion picture is a fair representation of the body form, the manners, and, may I say, the morals of the dinosaurs. Had you looked at the earth from a distant vantage point in that far-off Mesozoic Era, you would have said, "How can any good ever come from this welter of blood-thirstiness and cruelty?" The world seemed to have gone mad. The emphasis was apparently placed upon brute strength and fighting power. And yet, scurrying out from under the feet of those ponderous dinosaurs were the first of the mammals, little, puny, weak creatures. In any combat, "man to man," a mammal would have been hopelessly outclassed by one of those gigantic reptiles. Nevertheless, the milestone that marks the end of the Mesozoic Era and records the birth of the Rocky Mountains marks also the downfall of those dinosaurs. They, and all their kith

Courtesy of the American Museum of Natural History

FIGURE 10. These three models of Eohippus, the Dawn Horse, were prepared by Charles R. Knight and faithfully portray the characteristics of this ancient member of the family of horses.

and kin, were blotted out of existence, and the mammals took their place at the centre of the stage, a position of importance and prominence which they have held even to this day.

Something other than mere strength determined survival value then. The mammals, among other things, had two inherent abilities. They had well-nourished heads, so that they put their confidence not so much in their brawn as in their brains, not so much in their weight as in their wits. Further, the mammals cared for their offspring. Most mammals have something of the spirit of coöperation, so that they customarily band together in herds or packs or clans. Especially in the strain that leads to man can we trace the increasing developpent of habits of coöperation. In other words, the earth has provided an environment which has favored not merely the development of the body form of its existing inhabitants, but has favored also the development of those other qualities which we call aesthetic or moral. Among the forces of nature there are those which tend toward an enlarging expression of psychical, yes, even of spiritual qualities. These, too, must have their survival value upon the path of life.

CHAPTER V

The Evolution of Mankind

MAN'S place in Nature is rapidly being discovered. His physical resemblance to other animals is so great that nobody who knows the facts can doubt for a moment that man is, like them, a product of the evolutionary process. Structurally, there is a greater difference between the monkeys and the apes than there is between the apes and man. In addition to the evidence from comparative anatomy, there are the many facts known to embryologists. Each human being begins existence as a single fertilized cell within the body of the female parent. There, for approximately nine months, the embryo develops, nourished and protected by the mother. During this embryonic history the unborn infant passes through a remarkable series of changes which are quite similar to the stages in the pre-natal history of other animals with backbones.

In all air-breathing vertebrates at least three pairs of gill arches are developed by the embryos. Between each two arches there is a projecting pocket, called a gill pouch. As the embryo grows, the foremost pair of gill arches become the upper and lower jaws, and the first gill pouch is converted into the middle ear. The second gill pouch never seems to have any particular function in reptiles, birds, or mammals, and yet it is always well

developed, an inheritance from the ancestral fish-like stage. The history of the individual is recapitulating the history of the race; "the past repeats itself in the present. In man certain structures arise within the first and second gill pouches which resemble rudimentary gills in form. Although they are close to large blood-vessels, they seem to have no blood supply and they persist only for a very short time early in the fourth week of development, leaving behind no trace." Similarly in the human embryo, a tail filament is conspicuously developed during the first few weeks of pre-natal history, and after the sixth week it too disappears.

When to the facts of comparative anatomy and embryology, is added the prehistoric record of the rocks, the evidence is overwhelmingly conclusive. Fossilized remains of man-like but distinctly pre-human creatures have been found at many localities in the last few years. The record is far from complete, but its bearing upon the problem of human origin is unmistakable. Almost certainly, additional relics of prehistoric man-like beings will be discovered in Asia, Europe, and Africa in the next few decades. Although these will doubtless throw much light upon the details of human evolution, the main outlines of the story are already known.

In the orthodox scientific classification of animal life, man and his nearest relatives, the apes, monkeys, and lemurs, are grouped together in an order to which Linnaeus long ago gave the name Primate. The primates are quadrupeds whose fingers and toes are protected

neither by hoofs nor by claws, but by flat nails; whose teeth are designed for the eating of fruits, nuts, and eggs, rather than the tearing of flesh or the cropping of grass.

The least man-like of this order are the lemurs. Today they are confined to the tropical parts of the Old World; many of them are small shy inhabitants of the forests of Madagascar. But fossil remains of the lemurs are found in the oldest deposits of the Cenozoic Era, the age of mammals, in North America and Europe. Evidently, lemurs were the first of the primates and lived in those continents shortly after the birth of the Rocky Mountains. The lemurs are long-tailed, squirrel-like creatures, quite at home in the trees where they grasp the branches between the four smaller toes and the big toe. This is characteristic of the tree-dwelling primates and is in contrast to the habits of other arboreal animals, like the squirrel, who maintain their hold upon the tree by digging sharp claws into the bark. Lemurs have fairly well-developed eyes, but they depend largely upon the sense of smell rather than upon sight. Thus they have a dog-like muzzle and nose.

Slightly more man-like, and therefore higher on the ladder of life from our point of view, are the tarsiers, tiny tree-living inhabitants of the East Indies. They have unusually large eyes, directed forward as are the eyes of a monkey or a man, rather than sidewise as in the lemurs. The dog-like muzzle of the lemurs has disappeared; the nostrils are reduced in size. The tarsier has a face, rather than a snout; sight has supplanted smell. Fossil remains

Courtesy of the American Museum of Natural History

FIGURE 11. Notharctus is the best known of the many primitive lemurs whose fossil remains are found in the older rocks of the Cenozoic Era. This creature was not far removed from the strain that led to man.

of tarsier-like animals are known from the older Cenozoic rocks of North America; but shortly after that stage of primate evolution had been attained, the primates disappeared from this continent. "From then until the time (not very many thousands of years ago) when the ancestors of the Indians entered this country, not one sure trace of a primate" is known to have been left in the record of North American life.

Next higher in the scheme of things are the monkeys. These are split geographically into two groups, one in the Old World and one in South and Central America. Evidently, before the primates disappeared from North America and while there was still a land connection between the two American continents, an expeditionary force had migrated to the southward. There they were isolated with the other South American animals by the breaking down of the isthmian bridge, and there they have remained to the present day, a side branch of the primate line which has never risen above the monkey level. Evolution toward mankind meanwhile progressed in Europe, Asia, and Africa, where the oldest fossil monkeys are found in rocks of the Oligocene period, the second period in the Cenozoic Era.

The monkeys are a distinct advance over the tarsiers. The eye of a tarsier is so constructed that the finer details of an object cannot be discerned, nor is there any depth of vision. In contrast, the eye of the monkey is essentially as perfect a mechanism as the eye of man. Monkeys walk on all fours, but sit erect upon the

haunches. Momentarily, the front feet are freed from the necessities of locomotion and are used as hands. With this development of eye and hand, there is a corresponding increase in mental ability, as indicated by size and shape of brain. Most of the animals who have remained at the monkey stage are tree-dwellers. Some, the baboons, have descended to the ground, but travel on all fours. Many monkeys have almost completely lost their tails.

In rocks of the same period as those carrying the oldest fossil remains of monkeys in the Old World, there are also the fossils of the most primitive of the anthropoid, or man-like, apes. The smallest, and least man-like of the existing anthropoid apes are the gibbons of south-eastern Asia and the adjacent islands. "They do not exceed three feet in height. In many details they still show resemblances to the monkeys. But the power of climbing and swinging upright among the branches is very highly developed in them and the arms are exceedingly long. The gibbon can walk erect, using its arms as balancers, but it is an awkward walker; its home is in the trees." Its brain capacity is less than a tenth that of the average man.

Next in the scale is the orang-utan, of Sumatra and Borneo. This is a larger beast, reaching a height of four feet, and a much more intelligent one, for its brain capacity is about a third that of man. "But the orang is still a tree-dweller; when it walks upon the ground, it does so in a bent position, resting partly on its knuckles at

Courtesy of the American Museum of Natural History

FIGURE 12. The tarsier is a nocturnal tree-dweller of the East Indies.

Courtesy of the American Museum of Natural History

FIGURE 13. The gorilla is the most man-like of the apes.

the end of the arms, which are nearly as long as those of the gibbon."

Much more man-like are the great African apes, the chimpanzee and gorilla, which attain a stature as great as five or six feet. In both, the arms are comparatively shorter than those of the orang-utan or gibbon, but still exceedingly long by any human standard. Both are quite large-brained; the brain capacity of the gorilla may be nearly half that of a white man. "In both, the eyes are buttressed above and behind by strong brow ridges. But in other respects they differ. The gorilla is by far the heavier and more powerful of the two. The chimpanzee is a moderately good walker, either aided or unaided by the hands, but is still essentially a tree-living type. The gorilla, on the other hand, is essentially a ground dweller and takes to the trees only for shelter. The gorilla, perhaps in correlation with its great weight, sometimes as much as 600 pounds, does not normally stand erect, but progresses on all fours on the soles of the feet and upon the knuckles." [1]

Search for fossil remains of primates ancestral to the chimpanzee, gorilla, and man has resulted in the discovery of teeth and fragments of jaws in the rocks formed in Asia during the Miocene and Pliocene periods, the third and fourth periods of the Cenozoic Era. The strata forming the Siwalik Hills of India have thus far proved most fruitful. Although the remains are, for the most

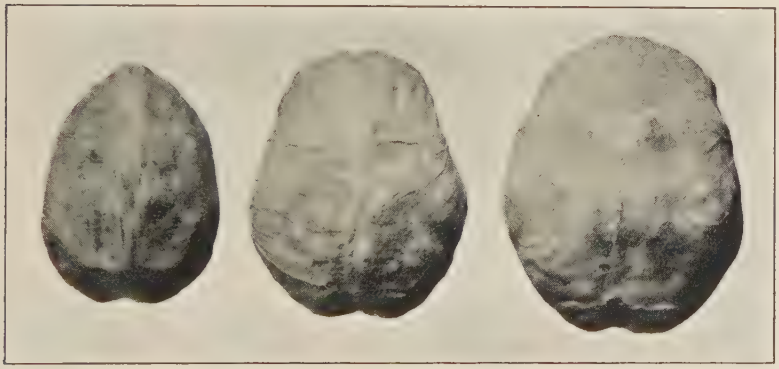
[1] A. S. Romer, "The Evolution of the Vertebrates"; chap. 11 in *The Nature of the World and of Man*, (Chicago, 1926), pp. 304–348.

part, mere fragments of the skeleton, it happens that the teeth are the most characteristic part of a mammal's anatomy and the most likely to resist destruction before they have a chance to become fossilized. The teeth from the Siwalik Hills have been very carefully studied, and it is now known that many of them possess features found in but three existing mammals — the chimpanzee, the gorilla, and man. Certain others indicate the divergence on the one hand of the ancestral strain leading to the two great apes, and on the other of the strain leading in a human direction. Evidently, to find a common ancestor for ourselves and the great apes, our nearest living non-human relatives, we must go back to the Miocene period, several million years ago.

Next in point of time in the geologic succession come the famous fossils found near Trinil, in Java, about thirty-five years ago. The enclosing strata were formed near the close of the Pliocene period or at the opening of the Pleistocene, the fifth period of the Cenozoic Era. This is the geologic period next preceding the present, and it was during this time that the Great Ice Age occurred. The Trinil fossils consist of the top of the skull, three teeth, and a thigh bone. They are the remains of a man-like creature, who stood erect but whose receding forehead and massive brow ridges must have had a distinctly ape-like appearance. His brain capacity was intermediate between that of a gorilla and that of the least intellectual of existing races of men. The frontal portion of the brain is comparatively small, but those parts with

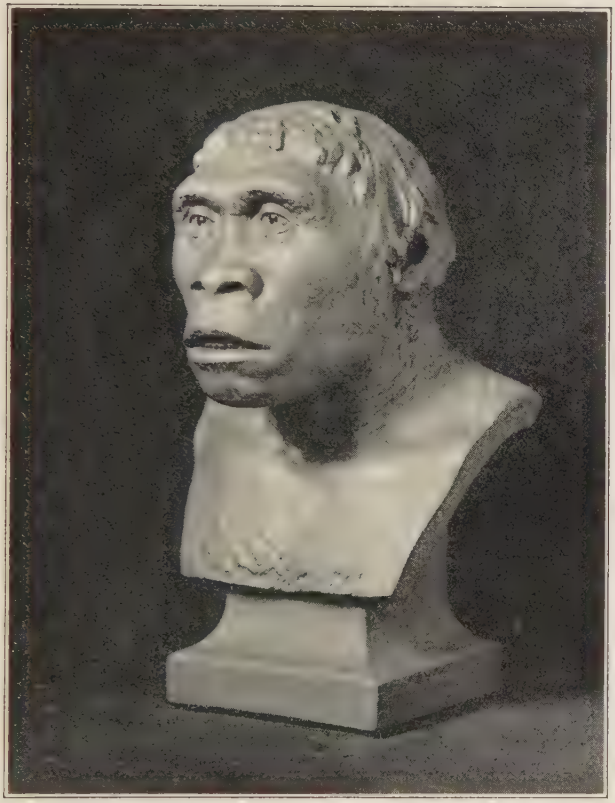
Courtesy of the American Museum of Natural History

FIGURE 14. The fossil remains of the Trinil "ape-man" consist of the skull-top, a femur (the bone in the leg, between hip and knee), and three teeth.



Courtesy of the American Museum of Natural History

FIGURE 14a. The brain of the Trinil "ape-man" was intermediate between that of an ape and that of a modern man. These are casts of the brain cavity within the skull of a large gorilla, at the left, within the Trinil skull-top, in the middle, and within the skull of a native of Rhodesia, at the right. In each instance the front of the brain is at the top of the picture.



Courtesy of Professor J. H. McGregor

FIGURE 15. This restoration of the "ape-man of Java" was modelled by Professor McGregor on the basis of the fossil bones found at Trinil, Java, in 1891 and 1892. The four models represented in this and the following illustrations are on display in the American Museum of Natural History in New York City.

which it is believed that speech is associated are fairly well developed. The creature well deserves the name *Pithecanthropus erectus*, the "ape-like man who stood erect." It is not known whether he used his hands to manufacture tools or weapons, but his brain development suggests that possibility. No traces of human handiwork have been found associated with the ape-man of Java; but flints that were probably shaped by human hands are found in England in gravel beds of about the same age as the Trinil deposits, one or two million years ago.

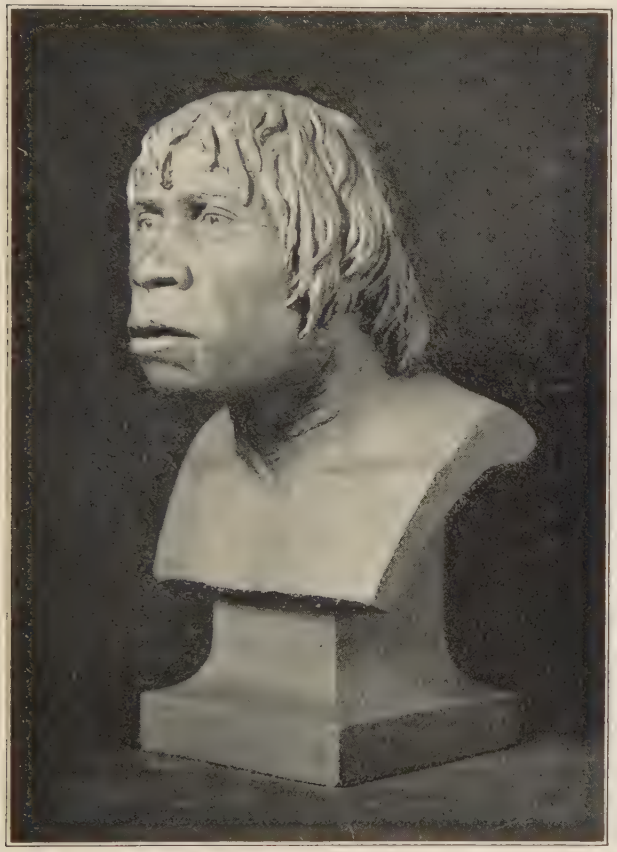
Within the last few months a part of a fossil skull of Pleistocene age has been discovered in South Africa. It has not yet been adequately studied but it is evidently the remains of a very advanced ape, more or less intermediate between existing apes and Pithecanthropus. It cannot itself be an ancestral form, for it did not live till long after the Java ape-man had died. It may represent one of the ancestral types, however, just as the modern lemurs represent the ancestral forms from which all monkeys and apes have sprung. The individual was very young, corresponding in age to a human child of six or seven, and therefore great caution must be used; for the skull of a young chimpanzee or gorilla appears much more human than does that of an adult ape. To this creature from South Africa, the name *Australopithecus*, or "southern ape," has been given.

The scene now shifts to Western Europe. During the Pleistocene period much of that region was repeatedly

covered by ice from great glaciers, which spread from Scandinavia and the Alps over all the surrounding territory. Four times the ice sheets advanced and retreated. There were thus three interglacial intervals and the short post-glacial time since the last glaciers melted away, only twenty or thirty thousand years ago.

During the first or second interglacial interval a considerable deposit of river gravel was made near Piltdown, in Sussex, England. A few years ago, the pieces of a skull and jaw were found in that gravel. Although the brow region of the skull is low, the brain capacity is as great as that found among primitive races to-day. But the jaw is chinless and ape-like, suggesting such an animal as the chimpanzee. The creature has been named *Eoanthropus*, the dawn man. With Pithecanthropus and *genus Homo* (to which genus existing men belong), it comprises the family *Hominidae*. It has been suggested that the ape-like jaw does not belong with the skull of Eoanthropus, but the argument seems settled by the more recent discovery, about two miles away in the same gravel bed, of a fragment of a second skull and with it a tooth of the type found in the original jaw. That a human skull should happen to be associated twice with the jaw of an otherwise unknown ape is exceedingly improbable.

Near Heidelberg, Germany, there was found about twenty years ago a fossil jaw of a very primitive man who must have lived during either the first or the second interglacial interval. The teeth are distinctly human, but the jaw lacks a chin and has many ape-like features. Per-



Courtesy of Professor J. H. McGregor

FIGURE 16. This model of the "Piltdown Man" was based on the skull and jaw found in 1912 at Piltdown, Sussex, England.

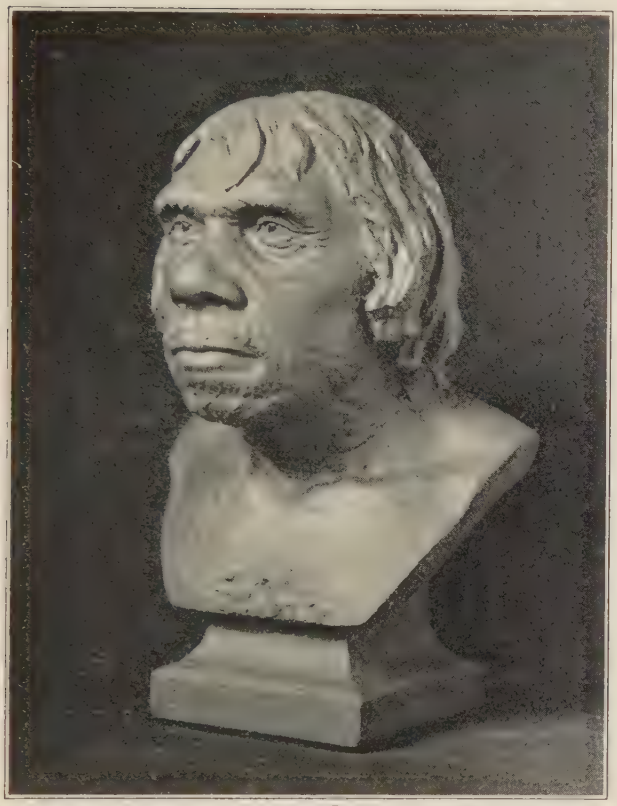
haps this Heidelberg man was ancestral to the next form to be considered. Probably he and his fellows were responsible for the artificially chipped, though very crude, stone implements of those early interglacial times.

The Neandertal man, *Homo neandertalensis*, lived during the third interglacial interval. Many complete skeletons have been found in caves in France and adjacent countries, and stone implements which he made are widely scattered throughout western Europe. His brain capacity was similar to that of modern men, but the forehead was still low, the chin retreating, the face projecting, and great brow ridges shaded his eyes. He walked erect, but with the knees somewhat bent; his large hands still lacked the flexibility of our fingers and thumbs. "He is a man, in a broad sense, but a man with the mark of the ape still upon him." Therefore, although referable to *genus Homo*, he is rated as constituting an extinct species.

The existing species, *Homo sapiens*, to which you and I belong, is first recorded in Europe as the last great ice sheets were melting away. Then the Cro-Magnon and allied races took over the land from the decadent Neandertal people. These newcomers were possessed of bodies essentially the same as those of existing races, with brains and faces of the truly human type. Old Mother Earth had produced not merely mankind, but *man*.

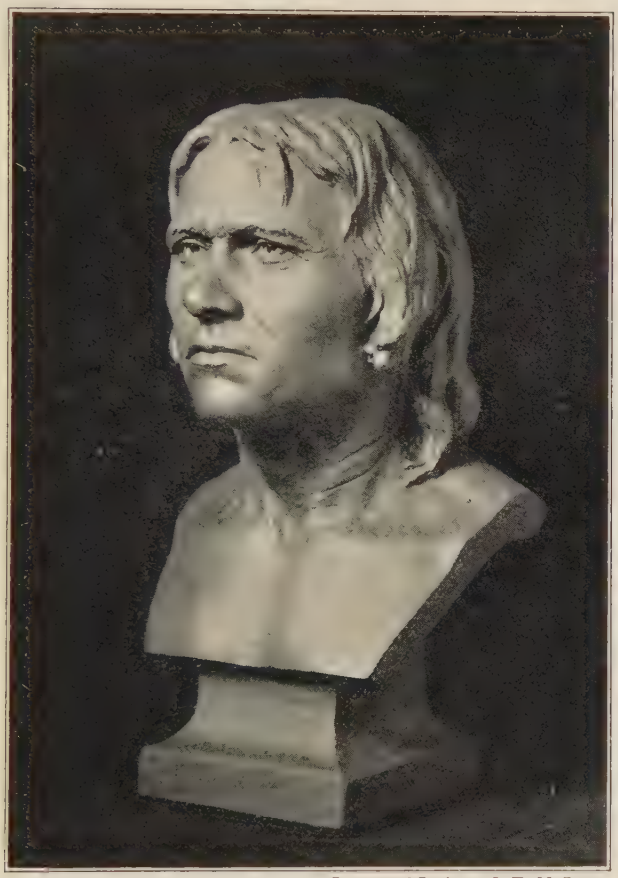
As the geologist surveys the procession of life during past ages, he witnesses the rise and fall of dynasty after

dynasty of animals and plants. He has seen the reptiles succeeded by the mammals. To-day we are observing how man in turn is triumphing over other animals. Quite naturally his thoughts turn to the future. "Will some other type of creature arise to supplant us, as we have supplanted our mammalian relatives? Or is something better, something finer, to come from man himself?"



Courtesy of Professor J. H. McGregor

FIGURE 17. Many skeletons of the "Neandertal man" are now known. The skull found at La Chapelle-aux-Saints, Carreze, France, in 1908 was used by Professor McGregor as the basis for this restoration.



Courtesy of Professor J. H. McGregor

FIGURE 18. The most ancient race of the existing species of mankind lived in Europe twenty to thirty thousand years ago. The skull of the "Cro-Magnon man" found at Les Eyzies, Dordogne, France, in 1868 supplied the data for this head modelled by Professor McGregor.

CHAPTER VI

The Philosophy of Evolution

EVOLUTION is the keystone of the arch that modern science is constructing to bridge the chasm between the ignorance and superstition of yesterday and the wisdom and faith of to-morrow. Every department of science is permeated by the evolutionary concept; no rational appraisal of the world in which we live can escape from its trend. Evolution simply means that everything known to us has come into existence through the orderly transformation of matter and energy in accordance with law. Thus the solar system has evolved from a previously chaotic and nebulous state; the first forms of life upon the earth have evolved from preëxisting inorganic substances; the more complex creatures, including man, which constitute a large fraction of the present population of the earth, have come into existence through descent with modification from preceding generations of animals and plants.

Evolution knows no beginning or ending. Our minds refuse to rationalize any process of making something out of nothing. We can think intelligently only of transformation, not of creation in the philosophical meaning of the term. The evolutionist, as such, is not concerned with ultimate origins or final destinies of anything or anybody. He attempts to describe the sequence of cause

and effect involved in every change of form or condition; he hopes to discover the laws which control the transformations which occur. Evolution, strictly speaking, is thus in the realm of natural science, not in that of philosophy or religion. Nevertheless, the evolutionary concept of the universe has a most significant bearing upon philosophy and a tremendous impact upon religion.

It is sometimes stated that evolution is in direct opposition to the Christian religion, or even that acceptance of the evolutionary principle makes necessary the abandonment of all belief in God. To many, the title of Bergson's masterpiece, *Creative Evolution*, means that evolution is a power which men of science wish to enthrone in the place of God. In Carruth's well-known poem,

> A fire-mist and a planet,
> A crystal and a cell,
> A jelly-fish and a saurian,
> And caves where the cave-men dwell;
> Then a sense of law and beauty,
> And a face turned from the clod,
> Some call it Evolution,
> And others call it God,

there is the implication that God and Evolution are synonyms. Obviously, from such suggestions, it is very easy to reach the conclusion that there is not room for both God and evolution in one's philosophy, and that one of the two must be abandoned.

But there is a tremendously significant fallacy in such reasoning. Evolution is not a power or a force; it is a process, a method. God is a power, a force; he neces-

sarily uses processes and methods in displaying power and exerting force. Many of us believe that science is truly discovering in evolution the process and methods which God, the spiritual power and eternal force, has used and is using now to effect his will in nature. We believe that, the more we know about these processes and methods, the more accurate knowledge we possess of the nature of God and of his will concerning man. It is in that sense that the scientist "thinks God's thoughts after him."

Again, there is the idea that evolution is a debasing concept which tends to level man down to the plane of the beasts. To many persons the thought of human evolution from the "lower animals" seems to be repugnant, if not almost shocking. The time-worn question "Was your grandmother a monkey?" is an indication, not only of the ignorance of the questioner concerning the scientific conception of man's origin, but also of his large residue of the superb egotism which seems to characterize the human species. The same self-satisfaction which led Linnaeus to classify man as "Primate" in his subdivisions of the animal kingdom has long been fostered in many quarters. Collectively, it is man's mission, we are told, to subdue the earth, to rule among the creatures whose only excuse for existence is that they may minister to his comfort; while enjoying the fruits of the earth, he is preparing for a heavenly home which he merits because he is only a little less than the gods. Individually, he has been taught to revere his ancestors,

to set as his goal of perfection the good old days and the good old ways of a past more or less remote. How can these things be, if his origin is the same as that of the beasts of the field, if in every fibre of his being there is that which makes him kin to the animals destined to contribute even their lives to his welfare? No wonder the smug philosophy of self-centred mankind is rudely disturbed by the evolutionary doctrine.

But this is a sadly warped view of the matter. Evolution really emphasizes the heights to which man has climbed, rather than the depths to which he has fallen. I had a college chum who used to say: "It is n't where a fellow came from, it's what he brought with him that counts." I trust he will pardon me if I apply the important truth contained in that sophomoric statement to the question in hand. Personally, I take just as much pride in my lineage from the unknown semi-brute who first "flaked a flint to a cutting edge," as I acquire on account of the other ambitious ancestor who first aspired to know the difference between right and wrong and therefore was driven from a garden of contentment into a world of problems.

To the scientist, of course, such considerations are quite irrelevant. He wants to know the facts, no matter how unpleasant they may be. "Truth is truth, if it sears the eyeballs." The man of science follows "wherever and to whatever abyss truth leads him," for he knows that "truth shall make him free." Even to the man of religion, the idea of relationship between man

and the so-called lower animals ought not to be repugnant. Surely those who insist that the African Bushmen or the South Sea Negritos are their "brothers" need not feel any repugnance at accepting the apes or even the monkeys as their remote "cousins." The essential unity of the human family is but an application of the evolutionary principle of kinship throughout the entire organic world.

As a matter of fact, however, evolution is not only a doctrine which is most flattering to man; it is also a principle that provides the strongest proof for the presence in the universe of a spiritual power worthy the name of God. The records of the evolution of mankind during preceding geologic periods clearly indicate that our ancestors possessed innate abilities which, when used to the full, enabled them to rise supreme above their competitors. Each chapter in the story contains its element of achievement and success. Their ability was in part inherent in their physical form and mental attainments — factors which can be directly studied by means of fossil remains and ancient manufactured articles. But man does not live by bread alone; the record of the rocks by no means tells the whole story of his ancestral achievements.

Man not only has an efficient and readily adaptable body; he also possesses a knowledge of moral law, a sense of rightness, a confidence that his reasoning mind finds response in a rational universe, and a hope that his spiritual aspirations will find increasing answer in a spirit-

ual universe. Such things as these cannot be preserved in the fossil record, yet their presence must be explained. Somehow, from the continuity of the evolutionary process real differences have emerged. When the cow pauses on the hillside to admire the view, or the dog ceases his baying at the moon to construct a system of astronomy, then and not till then shall we believe that there are no differences between man and other animals. Even though we may not understand how these differences arose, the facts are there. Knowledge and mystery have a habit of existing side by side; but mystery does not invalidate the fact.

To the scientist, man is a product of his environment. The eye, for example, is a response to something in the environment. That which we call light rays, coursing through space, has impinged upon sensitive protoplasm, the stuff of which all living bodies are made. As a response to this external stimulus, the splendid mechanism of the human eye has been developed through evolutionary processes during geologic time. Similarly, the human ear is a response to the external world. That which we call sound waves, pulsing through the earth's atmosphere, impinges upon sensitive protoplasm; and the delicate mechanism of the ear, far better in some other animals than in man, but still pretty good in man, is the result. But the scientist cannot stop there. Man possesses other attributes than those of his body alone. His yearning for truth, his appreciation of beauty, his desire to make his own life worth while in the world, his

sense of values, in short, the various attributes which we say pertain to his soul, are just as real as eye or ear. They, too, must be a response to something in his environment. That which we call the spiritual, permeating the universe, impinges upon sensitive protoplasm in the form of a quadruped mammal who stands erect and uses his front limbs as hands; and the human soul, not nearly so perfect as it some day may be, but still pretty good in the best of men, is the result. The causes must be adequate to produce the effects; the antecedents cannot be less than the consequents. To explain humanity at its best, the scientist must ascribe to the universe those qualities which we do well to call divine.

There has been a tendency to consider evolution as a purely mechanical process. To some, "evolution is the working of a great machine that never alters its mode of action nor the nature of its product. Science is the examination of what this machine does and produces. . . . Nothing essentially new or unexpected can come out of it." Therefore, after observing any small part of the evolution process and discovering any little sample of the laws of action, "the clever observer, armed with an adequate computing machine, could . . . predict the entire course of evolution; all that will occur or exist at any later period."

Diametrically opposed to this doctrine of mechanistic evolution is the doctrine of emergent evolution, which "holds that the conception of the universe as nothing but a set of one or a few kinds of particles moving accord-

ing to a few immutable laws . . . is pitiful in its inadequacy." According to this view of the evolution process, new things appear as evolution advances. "With these, emerge new methods of action, following new laws." Thus "new things and new modes of action distinguish the living from the non-living, the sentient from the non-sentient, the reasoning from the non-reasoning, the social from the solitary." That is, at each progressive stage in the history of Old Mother Earth new properties were acquired by its constituents as they emerged into a "higher" grade of existence. These new properties in the new surroundings were associated with new modes of conduct, new laws to determine action.

"Man, like other organisms, is an emergent. His actions may follow the same principles as those of other organisms, or he may act on different principles. This is not a matter for assumptions; it is all a question of fact, to be discovered by experiment; by experience and in no other way. What man has in common with other organisms is to be discovered by investigation and careful comparison, not taken for granted. Wherein he differs from other organisms; wherein he is unique — this stands on the same footing; it is purely a question of observable fact." [1]

The acceptance of the philosophy of emergent evolution permits the scientist to believe that ideas, ideals, purposes, and beliefs have an important function in the

[1] H. S. Jennings, "Diverse Doctrines of Evolution, Their Relation to the Practice of Science and of Life"; in *Science*, lxv, 19–26 (1927).

world; that when a man makes up his mind to do a certain thing he actually changes the course of history. With Huxley, we can say, "this world is absolutely governed by ideas." Out of a world governed by the law of gravity and the laws of atomic structure has emerged a world in which mentality is a powerful directing force, a world in which purpose does make a difference, a world wherein "intelligence is practical and a source of power." No longer must we believe that mankind is a victim of circumstance, that everything a man says or does or thinks is determined for him by forces outside of his control.

The statement that the laws of nature are immutable must not be construed to mean that new laws shall not be operative when new conditions arise. "Because things have occurred in a certain way in the past, it does not follow that they must thus occur in the future. This has not been the history of evolution in the past; there is no ground to expect it to be so in the future." The doctrine of emergent evolution makes it perfectly reasonable to hope and strive for the realization of ideals that have never yet been realized. And this is the evolutionary doctrine which in the last few years has been rapidly superseding the formerly popular doctrine of purely mechanistic evolution, because we are discovering that it is a far better explanation of the behavior of Old Mother Earth and her offspring than any other which has been proposed.

If ideas govern the world to-day, it is exceedingly important that our ideas concerning so significant a process

as evolution be correct. Ofttimes it is assumed that evolution necessarily implies progress; that if man has come up from so lowly an origin, he must inevitably continue climbing to still higher levels than those on which he now lives. But the record of the past does not justify that sort of fatalistic optimism. Evolution does not necessarily mean progress; it necessarily means only change. That past changes have resulted in what we are certainly justified in calling progress, is a fair basis for hope and faith that further progress will occur, but it does not guarantee progress. The only thing that evolution guarantees to man at the present moment is opportunity. The responsibility for making the most of the opportunity rests fairly and squarely upon man, individually and collectively. "Truth crushed to earth will rise again," only if some human being stoops down and lifts her to her throne.

From the unconscious minerals of Pre-Cambrian time there emerged the brute consciousness of the lower animals. The geologic eras succeeded each other for untold millions of years before there emerged from brute consciousness the self-conscious human being; but in a comparatively brief interval of time, self-consciousness is beginning to give place to an emerging world-consciousness such that men are daring to look all their fellows in the face with the eyes of a brother, and to act as if all men everywhere, regardless of color or intellect or nationality, are members of a single family. In this emerging ideal of brotherhood rests the hope for the world. It is the present high-water mark of the flood of evolution.

CHAPTER VII

Geology and Genesis

THE first chapter of the Book of Genesis provided the battleground a half century ago for the historic encounters between science, represented by such valiant warriors as Huxley, and theology as outlined by Bishop Wilberforce and his colleagues. Echoes of that conflict resounded from the hills of eastern Tennessee a short time ago, and in many quarters there seems to be a disposition to renew the encounter on the same old terrane. The modern student of the history of Old Mother Earth is frequently questioned concerning the present value or lack of value of the ancient records. Shall they be tossed into the discard as outworn folk-lore, or may they be of use to citizens of the twentieth century?

Only casual inspection of the opening chapters of the Bible is needed to indicate the fact that at least two separate accounts of creation are contained therein. The first occupies all of Genesis 1, and continues to the middle of the fourth verse of Genesis 2. It is a scientific statement of the origin of the earth and its inhabitants. In sober, straightforward language the patriarchs of Palestine were setting forth the results of their scientific observations and deductions. Limited though their knowledge was, they recognized something of the law and order which characterize the universe. The world could not

be the result of chance or accident; effects must have been produced by adequate causes; events must follow each other in regular sequence. For them, as for the modern scientist, there could be no thought of something coming from nothing; they made no attempt to consider an actual beginning, they could discuss only the transformations of that which had formerly been into that which now is. Unfortunately the King James translation robs the Hebrew document of part of its value in this connection by using the words, "In the beginning, God created the heaven and the earth." The real meaning of the passage is much more accurately rendered by such translations as that of Professor Moffatt: "When God began to form the universe, the world was void and vacant, darkness lay over the abyss." From the desolate wastes of the primeval chaos, the material universe was shaped. In an orderly manner the earth was formed and populated during the successive days of the creation week. At first lifeless, it became in turn the home of plants, of animals, and of man. Furthermore, the creator accomplished his purpose through the operations of natural law. "Let the waters bring forth abundantly the moving creature. Let the earth bring forth living creatures."

All this is fairly good science; but it is not modern science. It is obviously the science which was current in the year 500 B.C., in the countries bordering on the eastern Mediterranean. To the keenest observers of that time and place the world was just exactly what to

the casual, untrained observer of to-day it appears to be. Over the flat surface of the earth was arched the solid firmament, the vaulted dome of the heavens, in which were set the sun and moon, the greater and the lesser lights which climb upward from the eastern horizon and descend to disappear below the western. The stars appeared so near the Palestinian hill-tops that it seemed possible to build a tower tall enough for man to climb up and touch them. When it rained, the windows of heaven had been opened to permit the waters above the firmament to spill down upon the earth.

All this has long since been changed. The tiny vest-pocket universe of 2500 years ago has been expanded into stellar systems the dimensions of whose parts are to be measured in units known as light years. The central position of the earth, "fixed so that its foundations cannot be moved," has vanished; it is now a trivial speck moving swiftly in its orbit around a sun three hundred thousand times its own mass, and spinning upon its axis as it goes. The length of the day is determined, not by the velocity of the sun across a firmament, but by the rotation period of the earth itself. Though we still assert that the sun rises in the east and sets in the west, we know perfectly well that it does not do so at all, but merely appears so to do. Not that we have learned to distrust our senses; still is the world exactly what it appears to be. We have merely learned that hasty conclusions are apt to be erroneous, that the casual observer is not to be relied upon. We have many more facts of

observation from which to draw conclusions. Our senses have been made more efficient by telescopes and microscopes, transits and sextants; our recollections have been made more precise by records extending over centuries of time. Still must we take the world exactly as it seems.

With expanding knowledge of the facts, there is necessarily a great revision of the inferences concerning processes and methods, times and sequences. What for the patriarch of olden time was the work of six days of twenty-four hours each, for us requires geologic eons of untold millions of years. Although for him it seemed likely that the earth was formed before the sun, we now have abundant reason for believing that the earth is an offspring from that huge star, that the entire history of the planets is but an incident compared to the longer antecedent and future history of the sun. In minor details also is there obvious disagreement between the science of Genesis and the findings of modern geology. Whereas the ancient document avers that all forms of plant life were formed before any animals came into existence, we now know that the lower forms of animal life were present long before the higher plants appeared. Despite the remarkable insight displayed by the patriarchs of old, their statements are in many respects at variance with the conclusions of modern science. The science of the Bible cannot be harmonized with the science of to-day; nor is it worth while to attempt by clever twists of phrase or interpretation of words to bring the two into harmony. The advance of science neces-

Courtesy of Harvard College Library

FIGURE 19. This medieval interpretation of the "Creation of Adam" represents Jehovah at work on the sixth day of the creation week. It is one of the illustrations in the Nuremberg Chronicle, a history of the world published in 1493.

sarily involves the controverting of ideas and conclusions earlier believed to be established. And science has advanced since 500 B.C. By the same token we may expect that 2500 years hence, much of what we now believe to be true will have been replaced by more accurate understanding. Even the Einstein theory may then be looked upon as a part of the naïve and bizarre folk-lore of the twentieth century.

All of which means that it is hopeless to expect in Genesis 1 a satisfactory scientific account of how the world was made. The values of that document are historical and philosophical rather than scientific. The philosophers of olden time took the best description of the world which the keenest observers of their day could give them; to that description they gave just as spiritual an interpretation as they were capable of giving. Exactly the same policy should be adopted by the theologian of to-day.

The second creation story, which begins in Genesis 2:4 and extends through Genesis 3, is on quite a different plane. It is not science at all, and makes no pretense of being so. When a man talks or writes about a tree of knowledge of good and evil, he obviously is not referring to any physical, material tree, an apple tree or any other variety of orchard tree. He is using a figure of speech, presenting an allegory or parable, in the vivid picturesque imagery to which oriental minds have long been accustomed. We recognize such figures of speech in many parts of the Bible. "Ye are the salt of the earth" was

never believed by anyone to be a literal statement. Even so, it is doing violence to the second creation story in Genesis, if its beauty and value be destroyed by interpreting it as history. Parables and allegories such as this have an important place in literature and an abiding value in human minds and hearts, but they must be considered in the same spirit as that in which they were conceived.

Partaking of the fruit of the tree of knowledge of good and evil is a very real experience, both for each individual and for the human race as a whole. The patriarchs of Palestine had observed that one of the characteristics which distinguish man from other animals is his sense of moral law. And they were correct. Far back before the dawn of recorded human history certain ancestors of ours first said it would be right to do this thing, wrong to do that. A consciousness of moral law had emerged from the evolutionary processes which Old Mother Earth was directing. Man had partaken of the fruit of the tree of knowledge of good and evil. And more than likely it *was* a woman who first considered the moral consequences of human deeds, and then taught a man what she herself had learned. It was a real achievement, a major upward step in the progress of life, something of which we may well be proud and something which should clearly be distinguished from the so-called "fall of man." Not until human beings had attained a knowledge of good and evil could they be held morally responsible for their acts. Sin in the theological sense consists of wilfully

Courtesy of Harvard College Library

FIGURE 20. Fifteenth-century Christians believed that the "Creation of Eve," like that of Adam, was described literally in the book of Genesis. Like the preceding illustration, this drawing is from the Nuremberg Chronicle.

doing what one knows to be wrong. Man could not "fall" until he had climbed; he should be blamed, not for climbing, but for the subsequent falling.

The parable continues; man discovers that he is naked. Anthropologists tell us that primitive folk did not at first attire themselves in clothing through any sense of modesty. Doubtless they are right. My own observations among uncivilized Indians east of the Bolivian Andes led me several years ago to the conclusion that clothing there was designed as a protection against mosquitoes, midges, and gnats. Actually, modesty played no part in the determining of costume. Nevertheless, the adorning or covering of the body is a direct by-product of the consciousness of self, another characteristic which sets man apart from the animals which display no indication of being self-conscious. Doubtless the emergence of self-consciousness from the brute consciousness of the lower animals must have been more or less contemporaneous with the dawning recognition of moral law.

Similarly the statement concerning the origin of man, set as it is in the midst of obvious figures of speech, should be considered as allegory rather than as science. Man is a creature of mixed motives and conflicting natures. At times he permits his animal instincts to rule his conduct; he exists upon a dead level with the beasts; he proves that he is of the earth, earthy. At other times he lifts his face toward the stars; he yearns for an understanding of himself and of his environment; he resolves to live a more useful life to-morrow than he has been

living to-day; he is of the heavenly, divine. How better could this important truth be crystallized in the Hebrew annals than by describing man as made of the dust of the ground and the breath of life! To ascribe to that statement the idea that man was literally manufactured from mud is a libel upon Genesis. It is equivalent to maligning modern science with the charge that evolution means that man is a descendant from a monkey.

The scientist is constantly asking the question, "how?" He studies the processes by which things have come to be as they are. The authors of the second creation story in Genesis were interested more in the question, "why?" They sought to find a basis for a philosophy of life, an explanation of the facts of human nature. Thus in Genesis 2:7 we find reference to the power, Jehovah; the raw material, dust and breath, matter and spirit; the product, man. Nothing is stated concerning the process or method used in transforming the raw material into the product. Evolution is the answer of modern science to the question left untouched by the philosophers of old. In a sense, therefore, it may be considered that science merely amplifies and expands the creation story with which we are now dealing. Actually, however, there is no contradiction here simply because that creation story contains no science whatsoever. Its values are to be discovered in the field of metaphysics rather than of physics, of religious philosophy rather than of natural science.

Those values are high, but they are by no means the

best that can be found in literature and life. The insight which the patriarchs had concerning the nature and characteristics of man seems to have far exceeded their insight concerning the nature and characteristics of God. Not only is the geology of Genesis unsatisfactory for modern man; its theology is distinctly non-Christian. For example, it is the orthodox belief that Genesis teaches that Adam and Eve were expelled from the Garden of Eden as punishment for the crime which they committed when they broke a rule and ate a forbidden fruit. Actually there is no such teaching in that book. The last three verses of the third chapter give the reason for the expulsion and reveal clearly the estimate of God which the ancient Hebrews had in 800 or 900 B.C. "Then said God, 'man has become like one of us, knowing good and evil. Now, he might put forth his hand and take also of the tree of life and by eating of it live forever.' Therefore God sent him forth from the Garden of Eden to till the ground from which he had been taken. He drove the man out, and set cherubims at the east of Eden with a flaming sword flashing in every direction to guard the path to the tree of life."

In contrast to that picture of a god who feared that men should be like gods and who did not want them to live forever, one hears an echo from the Galilean hillsides: "I came that ye might have life, and have it more abundantly. Be ye therefore also perfect even as your heavenly father is perfect." The follower of Jesus of Nazareth must be very far behind his leader if he has not

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advanced far beyond the theology of Genesis 1, 2, and 3. Citizens of the twentieth century do well to consider carefully those ancient documents and gather from them whatever truth they hold, but neither in religion nor in science can the inhabitant of the modern world return to the mental attitude of a member of an ancient Hebrew tribe. Rather should the partial success of the patriarchal poets and seers stimulate the modern seeker after truth to a similar enthusiasm and wonder as he contemplates the complex universe in which we dwell.

CHAPTER VIII

The Great Ice Age in North America

THE northern states and Canada are liberally strewn with great bowlders and irregular piles of gravel, sand, and clay quite unlike anything observable in the southern states. The huge bowlders may consist of kinds of rock quite unknown among the rock formations which form the solid shell of the earth at the locality where they now occur. Thus, loose blocks of granite, weighing many tons and apparently identical with the granite of central Ontario, are found resting on the sandstone or limestone strata of southern New York, central Ohio, and central Illinois, hundreds of miles distant from the ledges of granite whence they must have been derived. Mounds or hillocks of sandy clay containing cobblestones, blocks and bowlders of a great variety of rocks, are scattered over hills and valleys. These materials are jumbled together without any assortment into layers, and the whole deposit looks as if it had been spilled out of a gigantic dump-cart. In contrast, the loose surface materials of the southern states consist essentially either of soil resulting from the weathering and decay of the underlying rocks, or of sand, gravel, and silt deposited in carefully assorted layers by flowing water. Furthermore, the landscape of the northern half of North America is dotted by thousands of lakes

and ponds scattered haphazard over the hillsides and valleys, whereas in the southern states the lakes are few and are nearly all confined to the bottomlands of the larger rivers.

So conspicuous is this contrast that it was noted nearly a century and a half ago, when the science of geology was in its infancy. At that time it was widely believed that the earth had formerly been a liquid ball, which cooled until a solid crust was formed. The rocks of that original crust were of course the primary rocks of the earth, and that name was for a long time applied to the granites and similar rocks which have crystallized from a molten state. Other rocks were observed which had been derived from these primary rocks. The grains of sand in a sandstone had come from the quartz crystals of the granite; even tiny pebbles of granite were discovered in some of the coarser sandstones. These derived rocks were therefore labelled Secondary. Still other rocks consisted of pebbles and other derivatives from the Secondary rocks, and they in turn were named the Tertiary formations. Fragments of the Tertiary rocks were noted in the loose débris which mantles the surface of the northern part of Europe and North America, and therefore the name Quaternary was given to this fourth system of rock materials. We know, to-day, that the so-called Primary rocks are by no means the oldest rocks of the earth and that they were themselves derived from previously existing mineral matter. In consequence, the names Primary and Secondary no longer have a place in

FIGURE 21. Bowlders and blocks of rock such as this huge stone near Lawrence, Massachusetts, were picked up by the advancing ice and transported for scores of miles when the great glacier spread southward across the northern states during the Great Ice Age. When the ice melted, these "erratics" were dropped helter-skelter and now are conspicuous features of the landscape at many places within the glaciated area.

the vocabulary of the geologist. This robs the terms Tertiary and Quaternary of their original significance, but those terms are still used to denote the last two periods of geologic time. It was during the Quaternary Period that the geography of North America attained its present character and the various loose materials were spread as a veneer upon the surface of the continent. It is in the Recent Epoch of the Quaternary Period that human history has been recorded.

Faced by the problem of explaining the nature and distribution of these Quaternary deposits, the first American geologists took refuge in theology. The Deluge, recorded in the Bible and made famous by Noah's achievements in naval architecture, was then believed to have been a world-wide catastrophe. Impetuous floods of water were conceived as dashing across North America from the northwest, sweeping huge blocks of rock as big as houses from their moorings, and transporting them for scores or hundreds of miles to deposit them on hill-tops or mountain-sides as the flood subsided. Ingenious explanations of the Flood were promptly forthcoming when sceptics raised their voices to doubt the ability of rain to furnish an adequate supply of water for so gigantic a task. It was suggested, for example, that vast lakes had burst their barriers during terrible earthquakes, or that the earth had suddenly stopped rotating so that the ocean waters thus pitched forward rushed pell-mell across the continent. Another clever idea involved the shifting of the earth's axis so that the polar ice-caps would be directly

beneath the sun. The swift melting of the ice would liberate devastating floods, which would swell the Arctic Sea to such proportions that it would become a boundless ocean, "which was propelled with inconceivable rapidity across the continent into the Gulf of Mexico, and probably over the unpeopled wilds of South America into the southern ocean. Fulfilled in this way were the awful denunciations of an offended God, by the sure extermination of every beast of the field and every creeping thing that crawled upon the face of the earth." [1]

This last suggestion, modified to suit one's personal whims, was quite popular for many years. Indeed, new information concerning the drift, as the Quaternary materials were then generally called, seemed to strengthen the argument in its favor. It seems to have been the superintendent of a cotton mill at Vernon, Connecticut, one Peter Dobson, who first printed a detailed and accurate description of the bowlders in the drift. The surfaces of many of these stones are scarred and scratched; smoothed faces on some of them are deeply furrowed. Dobson accounted for these markings by suggesting that the bowlders had been dragged over rocks and gravelly earth when held in the firm grip of ice. The drifting icebergs of the Labrador coast he thought might well illustrate the conditions of their production. Such icebergs might have come from the melting of the polar ice-caps, and would have been swept southward in the flood waters of the Deluge.

[1] H. H. Hayden, *Geological Essays*, published in 1820.

FIGURE 22. This rocky ledge near Clinton, Massachusetts, displays clearly the work of the great ice sheet in sculpturing the floor over which it advanced.

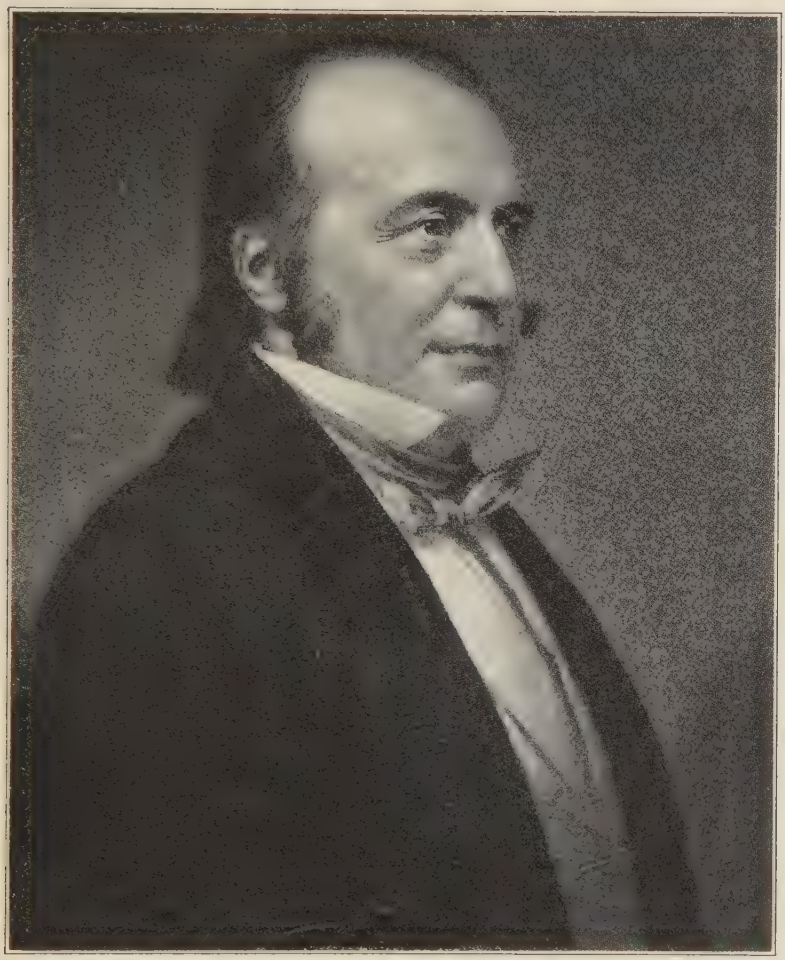


FIGURE 23. Shortly after Louis Agassiz came to the United States in 1846, he convinced most American scientists that the northern part of this continent had recently been buried beneath a great sheet of ice.

In 1846 Louis Agassiz came to America; but before that time he had advanced the idea "that at a period geologically very recent, the entire hemisphere north of the thirty-fifth parallel had been covered by a sheet of ice possessing all the characteristics of the existing glaciers in the Swiss Alps," a region with which he was very familiar. Such an ice-sheet would easily account for all the phenomena of the drift and for the peculiarities of the landscape in the northern lands. The glacial theory met with strong opposition from many of those who had committed themselves to the notion of a catastrophic deluge, but gradually it gained adherents, and by 1880 had become one of the accepted principles of geology. Many were converted to it by the discovery of an overhanging cliff in Scotland, with glacial grooves, scratched deep into the face of the rock on the under side of the ledge. It might be debatable whether floating icebergs could gouge the solid rock where they ran aground, but certainly no iceberg could scar the under side of an overhanging ledge. Only glacial ice pushed firmly against the cliff and sliding past its face could leave such marks.

Ideas concerning the ice-sheets of the Great Ice Age in North America have been radically altered since the time of Agassiz, but to him goes the credit for proposing and establishing one of the most important of geological principles. We now know that, instead of one great polar ice-cap, there were several separate ice-sheets. In North America the two largest had their centres in Canada; east of Hudson Bay was the Laurentian Sheet, and west

of Hudson Bay was the Keewatin Sheet. In each of these localities the snow accumulated for many centuries until the weight of its thick mantle caused its lower portion to recrystallize into ice. The ice increased in amount until it began to bulge outward and expand over the land, moving outward in all directions from its centre. The two ice-sheets coalesced along a line trending southwestward from Hudson Bay toward northern Minnesota. The southern margin of the compound ice-sheet crept onward, and at one time the edge of the ice reached St. Louis, Missouri, Cincinnati, Ohio, Olean, New York, Perth Amboy, New Jersey, and extended eastward along the "backbone" of Long Island, at least as far as Nantucket.

Furthermore, we now know that the Great Ice Age had a very complicated history, involving the formation, advance, and retreat of several successive ice-sheets, which in turn occupied much the same territory. Five times the ice spread out from the Keewatin and Laurentian centres, scraping the loose débris from the solid rocks upon which it moved, carrying bowlders and pulverized rock outward in the direction of ice movement, and reaching a maximum position somewhere near the places just mentioned. Five times the climatic pendulum reversed its swing, and the temperature of the ice-covered lands gradually was raised until the ice melted away, leaving its load of transported material strewn broadcast over the land thus freed from the grip of the glacier. The five glacial stages and the intervening four inter-

FIGURE 24. THE UNITED STATES AT THE CLIMAX OF THE LAST STAGE OF THE GREAT ICE AGE.
The ice-sheets are shown entering the United States from Canada and the areas covered by earlier glaciers are diagonally ruled.

glacial intervals constitute the Pleistocene Epoch of the Quaternary Period; the time since the retreat of the fifth and last series of ice-sheets is known as the Recent Epoch.

During at least one of the four interglacial intervals the climate of North America was warmer than it is now. Osage oranges, paw-paws, and locust trees grew near Toronto, well beyond their present northern limit. Fossil leaves of these and other plants are preserved in beds of clay and sand, which intervene between bowlder clay of an earlier glacial episode and the drift deposited by the latest ice-sheet at that place. There is no way of accurately measuring the length of these interglacial intervals, but it is quite certain that even the briefest of them was several times as long as the time that has elapsed since the retreat of the latest glaciers. That space of time is known fairly accurately and is in the neighborhood of 25,000 years. In all probability the first of the Pleistocene glaciers in North America crept southward into the northern states at least one million, and possibly two million, years ago.

As the several successive ice-sheets spread outward from their centres of accumulation, their movement was greatly influenced by the topography of the land. The ice advancing southward from Quebec entered the St. Lawrence Valley and then climbed up the northern slopes of the Adirondack Mountains. Although it succeeded in reaching and covering the very summits of those mountains, it was greatly retarded by them. In con-

sequence, a great lobe of ice projected far to the south down the Champlain–Hudson trough east of the mountains, and another lobe extended far to the southwest along the Ontario–Erie depression, whereas the main body of the ice did not everywhere cross the New York State boundary into Pennsylvania. Similarly, the broad depression now occupied in part by Lake Michigan shunted a part of the ice due southward along its axis, while another lobe was moving westward in the Lake Superior trough. In consequence, a considerable area in southwestern Wisconsin and northwestern Illinois was left free of glacial drift.

Such depressions as the Hudson River Valley and the troughs now occupied by the Finger Lakes in southwestern New York were directly in line with the ice movement. These were gouged deeper by the ice, and their sides were scraped comparatively smooth. The splendid cliffs along the Hudson near West Point and at Bear Mountain are examples of the combination of glacial and river erosion which has given them their present form. The bare rocks of those cliffs still display the polished surfaces and deep scratches which are the glacier's own autographic record of its former presence. Many of the beautiful rock-rimmed lakes in the Adirondacks are a result of glacial gouging, while the Finger Lakes and even the Great Lakes occupy basins which are due in part to glacial erosion.

As the ice-margin advanced southward it moved into a slightly warmer climatic zone. The rate of melting in-

Courtesy of the American Museum of Natural History

FIGURE 25. Storm King is one of the bold cliffs along the Hudson River, which owes its present form in large degree to the sculpturing accomplished by the ice of the Great Ice Age. The West Shore railroad is at the foot of the cliff; the Storm King Highway for vehicular traffic is on the narrow ledge carved in the face of the rocks, high above the river.

FIGURE 26. Raquette Lake and similar bodies of water in the Adirondacks occupy depressions excavated by the great ice-sheets or formed by the irregular deposition of the glacial drift as the ice melted.

creased, and finally the loss by melting exactly equalled the supply of ice from the interior of the ice-sheet. For a time its edge was comparatively stationary, as cubic mile after cubic mile of ice advanced and melted at the margin of the great glacier. The water issuing from the melting ice carried away great quantities of sand and gravel which were spread along the beds of the streams flowing southward from the ice-sheets. But much of the load which the ice brought was left near its margin in the form of irregular hills and ridges. These constitute the terminal moraines, quite analogous to those now being formed at the lower ends of the glaciers in the Alps or the Canadian Rockies. The most conspicuous terminal moraine extends westward from the Atlantic coast in northern New Jersey. It marks the limits of the area covered by the latest ice-sheets, and is generally a zone, a few miles wide, of small knobby hills with lakes and ponds thickly strewn among the intervening depressions.

Then the climate slowly became warmer. Melting exceeded snowfall upon the ice-sheet, causing its margin to retreat as the supply of ice failed. But the climatic change was not steady, and the oscillations of temperature from century to century caused the retreat to be a very irregular one. At times the ice-edge would remain stationary for a long time or even advance again over the land from which it had recently withdrawn. In consequence, there are many recessional moraines which mark temporary halts in the retreat of the ice. In some localities the ice advanced into the moraines which it had

recently deposited, and ploughed them into gigantic furrows. Some of the hills of drift were over-ridden by the ice and shaped into elongate oval patterns with smooth, regular crests and slopes. Such hills are called drumlins, and there are many of them in eastern Massachusetts and central New York.

But the increasing warmth of each post-glacial interval forced the ice-sheets finally to disappear, leaving a thin veneer of drift and scattered bowlders, the ground moraine, over all the area where they had been. In general these glacial soils are unusually fertile. In fact, our neighbors across the boundary line in Canada really have some cause for complaint at the partiality of Old Mother Earth in using the glaciers as the implements with which to scrape millions of tons of fertile soil from the hills and valleys of Ontario and Quebec in order to improve the agricultural resources of the northern states. We here in New England may look upon the ice-sheets as rather mixed blessings, for the infertility of the bare, gaunt New England hills is largely a result of similar glacial erosion, whereas the many falls and rapids in New England streams are available for water power chiefly because of the effects of the ice in the Great Ice Age.

Photograph by Douglas W. Johnson

FIGURE 27. This moraine near Falmouth, Massachusetts, with its irregular hills and basin-like depressions marks a temporary halt in the recession of the ice-front during the latter part of the Great Ice Age.

Photograph by Wallace W. Atwood

FIGURE 28. Ice-carved basins and glacially sculptured hillsides indicate that all except the highest summits of this portion of the San Juan Mountains was covered by the glaciers of the Great Ice Age.

CHAPTER IX

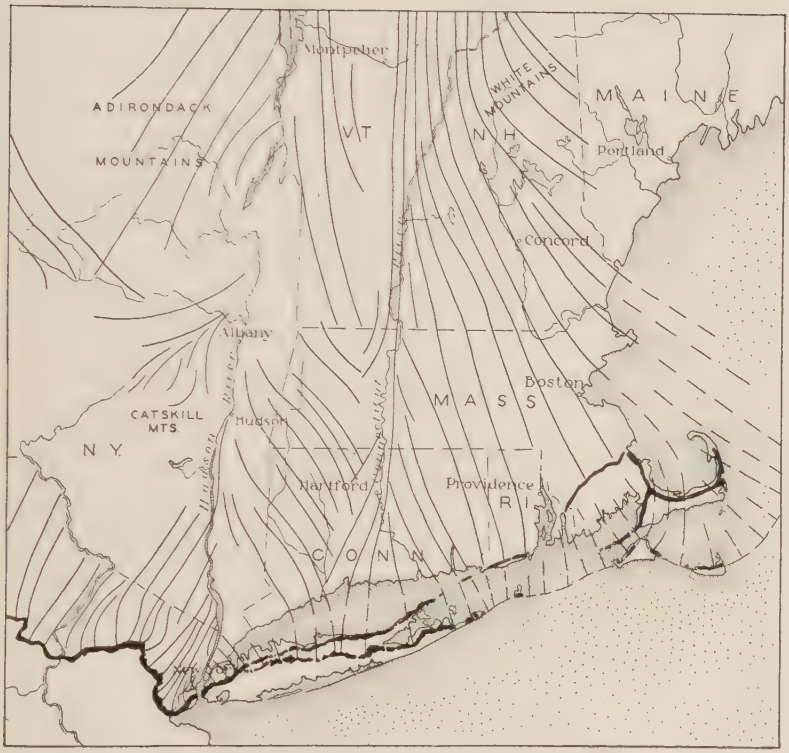
The Great Ice Age in New England

WHEN the ice-sheets of the last glacial stage of the Great Ice Age reached their maximum dimensions, New England was completely buried beneath ice. Even the summits of the White Mountains, the Green Mountains, Mount Katahdin, Mount Monadnock, and Wachusett Mountain were overtopped by the vast sheet of ice which had spread outward from its centre of accumulation east of Hudson Bay. At places this ice-sheet must have been at least 5000 feet thick and probably was considerably thicker than that, but there is no way of knowing how deeply buried were such mountain crests as the summit of Mount Washington. Judging by comparison with the existing Greenland ice-cap, the ice was probably 2000 or 3000 feet thick in central Massachusetts.

The southern margin of the ice-sheet at its maximum position is clearly indicated by the terminal moraine which forms the backbone of Long Island, extending eastward from Brooklyn past Lake Ronkonkoma to Montauk Point, the more southerly of the two flukes at the east end of the island. Farther eastward the moraine is now largely submerged beneath the Atlantic Ocean, but portions of it are above sea-level and form Block Island, Martha's Vineyard, and Nantucket. The eastern

margin of the ice-sheet at its maximum expansion must have rested upon lands that are now submerged, an unknown distance east of Cape Cod and Cape Ann.

At that time the relations between land and sea were notably different from those which are maintained to-day. The fact that the terminal moraine marking the edge of the ice is now largely submerged does not mean that the ice pushed out into the sea. Certainly it did not do so at the south, although it may have done so east of Boston. In general, the land near and at the margin of the ice stood about 200 feet higher with respect to sea-level than it does to-day. This relatively higher position of the land resulted chiefly from two important consequents of the presence of the ice. First, the water imprisoned in the ice-sheet had come from the sea to descend as snow upon the land, and represented an appreciable part of the oceans. Reasonable assumptions concerning the thickness, and therefore the volume, of the ice indicate that this temporary withdrawal of ocean water would lower the sea-level about 150 to 190 feet on the average, the world around. This would be offset in part by the gravitative attraction of the ice-caps themselves, which would greatly distort the sea surface by drawing up the water toward their margins. Thus sea-level would be lowered still more in the equatorial regions, but the amount of lowering would be decreased by a score of feet near the ice-cap along the north Atlantic shore. In the second place, the weight of the tremendous load of ice had a most depressing effect upon the land on



After Goldthwait in Antevs, Recession of Last Ice Sheet in New England.

FIGURE 29. On this map of the principal glacial features of New England the terminal moraine and earlier recessional moraines deposited by the last ice-sheet are shown in solid black; the general direction of ice movement is represented by the heavy lines which lead to the terminal moraine.

which it rested. Sinking of the earth's crust beneath the ice was necessarily accompanied by uplift of the crust in the zone beyond the ice margin. Indeed it is highly probable that the land just beneath the thin ice at the glacier front was raised with this zone of marginal uplift rather than depressed with the land farther northward beneath the thicker ice. Crustal deformation thus combined with sea-withdrawal to give the present north Atlantic shore from Cape Hatteras to Cape Cod an elevation which at most places approximated 200 feet above sea-level when the last ice-sheet was at its maximum dimensions.

There had been earlier ice-sheets during the Great Ice Age in New England. As stated in the preceding chapter, the Mississippi Valley was five times invaded by ice-sheets from the north during the Pleistocene Epoch of the Quaternary Period. Deposits made by at least three successive glaciers are present on Martha's Vineyard and have been tentatively identified in southern Maine and elsewhere in New England. But for the most part the vigorous erosion accomplished by the last ice, as it was advancing southward, resulted in the complete obliteration of the records left by earlier ice. Little is therefore known concerning them, and they are of slight importance in any explanation of the existing natural features of this area.

There was, however, a very interesting type of glacial feature produced before the last ice-sheet had covered New England. While the ice was spreading from Quebec

into New England, the crests of the White Mountains were mantled with perennial snow. Just as to-day in the Alps, so a few thousand years ago in the Presidential Range the snow accumulated in great banks nestling against the highest summits until the snow changed to névé and the névé to glacial ice. Valley glaciers scarred the sides of Mount Washington and carved great basins, called cirques, at the heads of the valleys in which they were moving. Tuckerman's Ravine, the Great Gulf, and Huntington's Ravine are the best known of these basins gouged by small glaciers, quite analogous to those now to be seen in Glacier National Park, before the great ice-sheet had spread over the White Mountains. These tiny glaciers, a half-mile or less in width and only two to five miles long, were of course swallowed up in the sheet of ice which crept southward a little later, but the results of their erosive activity are still plainly visible.

As the ice advanced southward it scrubbed its way across hills and valleys. The soil and weathered rock fragments which mantled the bedrock were scooped up and carried along in the glacier. At places the ice bit deep into the solid rock and rubbed away the projecting pinnacles and slender ridge-crests. Shallow basins were gouged out of the weaker rocks, and valleys trending in the direction of ice advance were deepened and smoothed. As a rule the northern slopes of hills bore the brunt of the ice attack. To-day they display rounded surfaces, whereas the southern slopes were generally left with jagged ledges and steep, step-like cliffs.

FIGURE 37. Looking down from an airplane upon the White Mountains in New Hampshire, Mt. Washington may be identified by the road and buildings upon its rounded summit, a little to the left of the centre of the view. The mountains beyond it are at a lower elevation, but appear to be higher because the camera was pointed obliquely downward. On the slopes of Mt. Washington, Tuckerman's Ravine at the left and Huntington's Ravine at the right are cirques occupied by small valley glaciers before the great ice sheet moved over the entire region.

Blocks of rock plucked from the abraded ledges or picked up from among the weathered fragments in the preglacial soil were scratched and rounded in the glacial mill. Some of these fragments were ground into the finest of rock flour, but many large bowlders escaped such destruction and were carried scores or hundreds of miles from their places of origin.

Cumberland Hill, near the northeast corner of Rhode Island, happens to be composed of an unusual and easily recognizable kind of rock. The heavy black bowlders from this hill are strewn over a narrow zone trending a little east of south past Providence and Newport. Another bowlder train has been observed in eastern Massachusetts, where blocks and cobblestones derived from ledges near Great Pond in Braintree are scattered southward as far as Great Pond in South Weymouth. The distribution of such bowlders transported by the ice, combined with the grooves and scratches on bedrock surfaces, indicates the exact direction of ice movement in most localities.

The autographs left by the ice on the bedrock over which it was moving are very numerous in New England and are unmistakable once their characteristics are known. Smoothly polished, rounded ledges generally display fine scratches or even deep grooves having in general a southerly trend. These were made by blocks of rock held firmly in the grip of the ice and pressed downward against the rock floor as the ice moved forward. Those on the granite hills near Quincy are particularly

conspicuous, and at many places in the Blue Hills the glaciated surfaces and grooves are easily recognizable.

As the ice advanced southward into warmer latitudes the rate of melting along its southern margin gradually increased. Finally the melting equalled the forward movement, and then for a time the edge of the ice was comparatively stationary. Each cubic mile of advancing ice brought forward its burden of bowlders and rock débris; much of this material was dumped upon the narrow strip of ground at the ice-front. Thus was constructed the terminal moraine extending the full length of Long Island, to which reference has already been made. Then came a change in the climate of North America, a gradual increase in the average annual temperature. In consequence, the ice melted away more rapidly than it advanced, and the edge of the ice-sheet began to retreat. But the retreat was not a steady one. Temporary decreases in temperature or increases in amount of snowfall caused slight readvances of the ice-front. Occasional halts in its withdrawal were marked by recessional moraines, one of the most conspicuous of which is the Harbor Hill moraine along the north shore of Long Island. This extends eastward as the more northerly of the two flukes at the east end of the island. Parts of this moraine are now submerged, but it reappears above the sea in Fisher's Island and along the south shore of Rhode Island west of Narragansett Bay. The spur of Cape Cod which forms the southeastern shore of Buzzard's Bay is another portion of this

FIGURE 31. As seen from an airplane, Crawford Notch, in the White Mountains of New Hampshire, displays the results of glacial erosion. A portion of the great ice sheet moving through this valley cleared it of all projecting spurs, smoothed its walls and left it with a U-shaped cross-section.

recessional moraine, and the greater part of the arm and fore-arm of Cape Cod consists of glacial drift dropped during this temporary halt in the recession of the ice-sheet.

During the readvance of the ice-front the ragged edge of the ice-cap would push forward into the hills of glacial débris which had been previously deposited by the melting ice. Where this happened, the ice-front would plough its way into the great piles of rock débris and might shape them into smoothly rounded hills called drumlins. These oval hills are generally between 30 and 150 feet in height and from one half to one mile long in a direction parallel to that of the ice movement. There are several hundred drumlins in the state of Massachusetts alone. Those west of Worcester have their longer axes in a north-south direction, while those near Boston trend from the northwest toward the southeast. Parker Hill in Boston and Corey Hill in Brookline are typical drumlins; so also are all of the larger hills in Everett, Chelsea, and Revere.

Near the margin of the melting ice, extensive deposits of sand and gravel were left by the water flowing away from the ice-sheet. The countless rivulets issuing from the melting glacier were capable of transporting the finer products of the glacial mill for considerable distances, but much of the coarser débris with which they were loaded was deposited in the form of outwash plains fringing the ice-front. These sand and gravel deposits range from 10 to 100 feet in thickness, and generally

had very flat surfaces covering one or two square miles in area. Many areas of flat land in and near Boston were made in this way. Typical of such sand-plains is one in the northern part of Newton Centre, between Mill Street and Commonwealth Avenue, stretching westward from Center Street, on which my own home happens to be situated.

As long as the ice-front was south of the basin now drained by the Charles River, the Neponset River, and similar streams emptying into Boston Bay, the water issuing from the melting ice was free to flow southward or southeastward to Narragansett Bay or Buzzard's Bay. When, however, the ice-front had retreated to a position north of the divide forming the southern rim of the Boston Basin, the escape of the water from the melting ice was hindered, and a series of temporary lakes was formed in front of the ice. The level of each lake rose until the lowest point in the surrounding rim of higher land was reached. There the lake found its outlet, and at that level the water stood until the farther retreat of the ice uncovered lower outlets. In the meantime these lakes received the débris washed out from the melting ice. This sediment was spread smoothly over the lake floor, and considerable areas of flat land quite similar to the sand-plains were thus constructed. One of the most interesting of these lakes covered about 30 square miles of the land east of the Blue Hills in Plymouth and Norfolk Counties. This vanished lake has been named Lake Bouvé in honor of

FIGURE 32. An early stage of Lake Bouvé is shown on this map of an area a few miles south of Boston. When the ice-front had melted northward to the vicinity of Randolph and South Weymouth, lakes were formed between it and the present divide at the south margin of the Boston Basin. The outlets of these lakes were southward across the divide into Narragansett Bay and Buzzard's Bay.

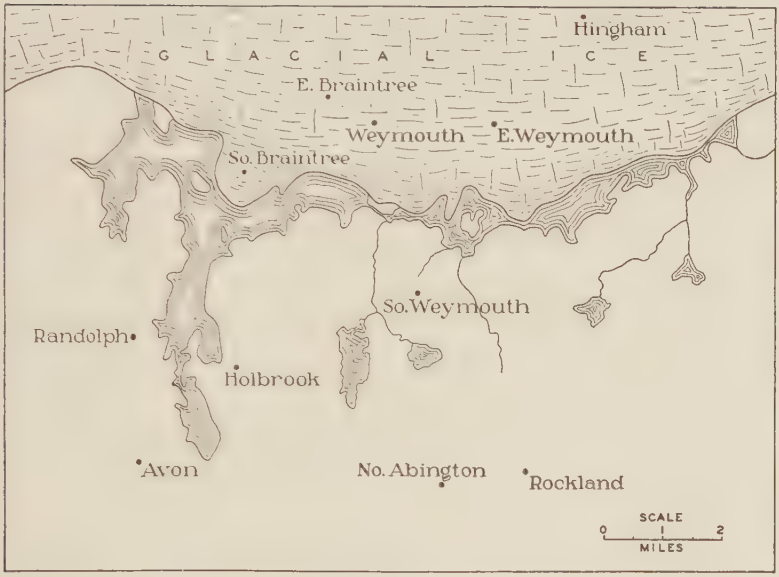


FIGURE 33. Farther retreat of the ice-front in the area south of Boston uncovered a lower outlet to the eastward and the water level of Lake Bouvé was lowered about 30 feet. At that time the relations of the ice to the lake were approximately those indicated on this map.

FIGURE 34. When the ice-front had retreated to a line north of Hingham, a still lower outlet for Lake Bouvé was uncovered at the northeast corner of the area shown in this map. Nevertheless many square miles of land between East Braintree and Hingham were beneath the water of the lake.

Mr. T. T. Bouvé, a former president of the Boston Society of Natural History and a life-long resident of Hingham. The area covered at one time or another by its water comprises nearly the whole of the present townships of Hingham, Weymouth, and Braintree, the eastern half of Quincy, and the adjoining portions of Randolph, Holbrook, and Rockland. The flat lands at Hingham Center and in the town of Quincy are typical remnants of the bottom of this lake, partially filled with sediment derived from the melting ice. Farther retreat of the ice permitted the waters of Lake Bouvé to drain eastward into Boston Bay, leaving the ponds in Braintree and Weymouth which occupy the lowest depressions on the old lake floor.

A long series of somewhat similar lakes was formed in front of the ice as it melted northward to uncover the Connecticut Valley. At that time the southern part of the Connecticut Valley stood higher than the portion near Springfield and Northampton, because of the sinking of the land beneath the weight of the great ice-sheet. The water escaping from the melting ice was therefore ponded in the valley. Later, with uplift of the land following the removal of the ice, the lakes in the Connecticut Valley drained out toward the south, and the present course of the Connecticut River was established.

The deposits made in those lakes a few miles beyond the ice-front consist of clay and fine sand, because lake currents are incapable of transporting coarse sand or gravel very far. During the summer both clay and sand

were washed into these lakes. The sand settled rather promptly to the bottom, but the fine clay remained in suspension, settling slowly through the water. During the winter months the lakes froze and the glaciers ceased melting. At this time the tiny clay particles settled to the lake bottom and formed a thin layer of very fine, dark mud. Year by year the layers of sediment accumulated, alternating between coarse, brownish-gray sandy clay for the summer months and fine, dark-blue clay for the winter months. In most of the brick yards in the Connecticut Valley, these bottom deposits of the vanished lakes supply the raw materials for brick and tile. By counting the number of layers in a clay bank, the geologist learns how many years were required for its deposition. It is also possible to correlate the annual deposits made at one place with those made elsewhere in the same valley. As a result of careful study of these laminated clays, it is now known that the time occupied by the retreat of the ice-front from Hartford, Connecticut, to St. Johnsbury, Vermont, was about 4100 years. This gives an average rate for the retreat of the ice-front of one mile in twenty-two years. Further studies of similar clays near New York City and in Quebec give information which leads to the conclusion that the ice was at its maximum extent about 25,000 years ago and required about 15,000 years to melt entirely away.

From the geological point of view that is a very brief interval of time, and the results of the glacial episode are therefore of far-reaching importance to the inhabitants

FIGURE 35. The face of this gravel pit near Needham, Massachusetts, reveals the characteristic structure of the "sand plains" formed at the margin of the retreating glacier in New England. Irregularly laminated beds of gravel and sand alternate with each other. This particular body of outwashed debris was evidently supported in part by the ice-front itself and when the ice melted away it settled slightly. In that way the miniature faults which off-set the beds along steeply inclined planes were developed.

of New England. The bare, gaunt New England hills are inhospitable to the farmer because the ice scraped away the fertile soil which had mantled them in pre-glacial time. The lowland plains, ancient lake bottoms, and valley flats are valuable farmlands because there the finer products of glacial erosion were deposited. The many cascades and waterfalls, which a century ago provided the power that made southern New England the most important industrial region in North America, are almost invariably the result of glaciation; as the rivers sought courses across the ice-freed land, they plunged over rocky ledges or soon cut their way down through the glacial drift to rock dams which crossed their paths. The scenic beauty of New England mountains and the countless lakes that dot the landscape are also to be attributed largely to the activity of the ice. Esthetically as well as practically, no chapter in the history of Old Mother Earth is of more importance to inhabitants of New England than the one that deals with the Great Ice Age.

CHAPTER X

What Caused the Great Ice Age

ABOUT fifty years ago, scientists in general accepted the theory of glaciation as a satisfactory explanation for the scattered bowlders and scratched rock surfaces which are so widespread in the northern states and Canada. Since then, much progress has been made in the determination of the exact details of the glacial story. The area covered by ice at various times and the work accomplished by the successive ice-sheets of the Great Ice Age are now fairly well known. The successive episodes in the retreat of the last glaciers, involving the history of Niagara Falls, of the Great Lakes, and of many other scenic features of North America, have been ascertained.

Although the facts of glaciation are known in considerable detail from the investigations of the last fifty years, geologists are still very much puzzled concerning what caused the ice to accumulate upon so large a part of this continent. Many possible causes have been considered. Some of them have been definitely rejected; others seem worthy of more careful study, and will be critically tested as knowledge increases concerning the laws which control the climate of the earth. No definite explanation of what caused the Great Ice Age has yet received the general approval of geologists.

When the fact of glaciation was first accepted, it was generally inferred that the refrigerated climate was an expression of the advanced age of Old Mother Earth. It was then believed that the history of the earth had been marked by the progressive and rapid loss of heat into space. The cold and dreary surface of the moon was inferred to be typical of the future state of the earth, a condition soon to be attained as its internal heat was radiated into space. According to this view the moon is cold and lifeless because its smaller store of original heat was more quickly dissipated; the larger body, the earth, pursuing the same history, eventually must succumb to the same fate. Coming events cast their shadows before. The recent glaciation was but a warning to indicate the close approach of the time when the aged earth would lose forever its genial warmth.

Unfortunately for this explanation of the Great Ice Age, it is now known that somewhat similar glacial climates have frequently recurred during earth history. There are glacial deposits among the oldest known rocks in Australia and Ontario. Just before the Appalachian region was folded into the great mountain system which stretches from New Brunswick to Alabama, there was a Great Ice Age, greater even than that of comparatively recent date to which we ordinarily apply that term. Some of the transported débris left by those ancient glaciers may now be seen as firmly consolidated rock at Squantum, only a few miles southeast from Boston. At that time, ice-sheets actually moved into what is now

the Tropical Zone in Bolivia and India. From the very dawn of recorded earth history down to the present day, there have been few geologic periods during which no record of glaciation was left somewhere upon the surface of the earth. Instead of being a unique incident late in earth history, glacial climates are now known to have been a rather common occurrence, affecting the earth in its early as well as in its later stages.

As a matter of fact, the conditions which determine temperature of the earth's surface are external rather than internal. The temperature of the earth's interior has very little to do with the climate of the earth's surface. Climate is determined by the condition of the earth's atmosphere, the relations between earth and sun, and the amount of heat thrown out into space from the sun. These conditions suggest the lines along which our inquiry should be directed.

At the present time there are two great ice-sheets on the surface of the earth, the Greenland ice-cap and the Antarctic ice-cap. The former is a body of ice which is slowly spreading outward in all directions from the central part of Greenland. Its centre is in latitude 73° north, which is about twelve hundred miles from the North Pole. The Antarctic ice-cap has its centre within a few score miles of the South Pole and at the present time covers the greater part of the continent of Antarctica. Obviously, if the North Pole could be so shifted as to place it somewhere near the southern tip of Hudson Bay, the Greenland ice-cap might easily be duplicated in approxi-

mately the same areas which were covered by the glaciers of the Great Ice Age. A change in the position of the earth with respect to the sun which would bring into polar latitudes the regions now in middle latitudes appears at first glance to be a very fertile suggestion. Astronomers tell us that such a change in the axis of the earth could not occur except under the tremendous and probably violent influence of some near-by heavenly body. No such body is now in the vicinity of the Solar System, and there is every reason for believing that the axis of the earth has maintained its present relation to the earth's interior and to the sun throughout all of geologic time. On the other hand, it is possible that the outermost shell of the earth may have crept forward or backward with respect to the earth's interior. The hypothesis of migrating continents is a spectacular theory now under consideration by geologists. One application of that hypothesis touches the causes of glaciation. Let the continents in turn and in appropriate times migrate so that the centres of the various glaciated areas would be near the North or South Pole. Thus, without any change in the climate of the earth as a whole, the development of local ice-sheets would be made possible.

Unfortunately for this theory of shifting poles, it is now known that during the Great Ice Age the continents were nearly if not exactly in their present latitudes. In the Americas for example, the altitudes at which glaciers formed in the high mountains of the west can be determined. At the head of each glaciated valley there is a

broad rounded basin called a cirque. The cirques were the gathering grounds for the mountain glaciers and were sculptured by them during the Great Ice Age. In Colorado the lowest cirques, now entirely free from ice, are at altitudes of 11,000 to 11,500 feet. In Mexico, a few degrees nearer the equator, the lowest cirques have altitudes of 12,000 to 13,000 feet. In Venezuela and Colombia the lowest basins in which glaciers formed during the Great Ice Age are at elevations of 12,500 to 14,000 feet. In Ecuador, approximately on the Equator, the lowest cirques formerly occupied by ice are now at elevations of 14,000 to 15,000 feet. Thus, as we approach the Equator from the north, we find, as we should expect, that the altitude necessary for the preservation of snow in sufficient quantities to give rise to glaciers is progressively higher. Crossing the Equator and working southward through Peru and Bolivia, we find that the requisite altitude steadily descends. In southern Peru glaciers formed during the Great Ice Age in basins at elevations of 13,000 to 14,000 feet. In the Bolivian Andes glaciated cirques may be observed at elevations as low as 12,500 to 13,000 feet. Farther south, in Chile, the ancient glaciers developed at elevations comparable to those necessary for ice to accumulate in the Rockies of Wyoming and Montana. Obviously, the earth's Equator had approximately the same relation to the mountains of western America during the Great Ice Age that it has to-day. The climate of the Great Ice Age cannot therefore be explained by assuming a poleward migration of North America.

Considerable attention has been given to the possibility of variation in the distance between earth and sun. As a major factor in the cause of glacial climates two suggestions are made by astronomy. There seems to be a periodic change in the shape of the earth's orbit, an ellipse, with one diameter about three million miles longer than the other. In consequence the earth at one time in the year is one and one-half million miles nearer the sun than it is six months later. It seems likely that there is a rhythmic variation in the amount of departure of the ellipse from a perfect circle. At times the difference between the two diameters of the ellipse is considerably more than three million miles and at other times it is less. At times of greatest eccentricity of the orbit, the earth would be appreciably farther from the sun than its farthest distance under present conditions. Again, we note that at present the earth is nearer to the sun in January than in July and actually receives from the sun more heat during the winter months in the northern hemisphere than during our summer. The winter season is determined by the fact that during those months when the North Pole is directed away from the sun the heat is largely appropriated by the southern hemisphere. With the change in relations of the earth's orbit which causes the so-called precession of the equinoxes, the time will come in a few thousand years when the northern winter will occur in the interval during which the earth is most remote from the sun. The northern winters will then be on the average somewhat colder than they are

now. It has been suggested that this difference, especially if it is exaggerated by a greater eccentricity of the earth's orbit, would be sufficient to cause glaciers to form in northern Europe and Canada. Both of these suggestions with respect to the relation of the earth to the sun fail to meet the requirements imposed by the Great Ice Age. These changes would result merely in varying the distribution of heat between summer and winter; the sum-total of the heat received by the earth from the sun would remain the same. To cause ice-sheets to form, cold summers are even more essential than cold winters. Apparently the Great Ice Age involved a world-wide cooling of the surface temperatures of the earth throughout the entire year. A drop in the average annual temperature of the earth as a whole, amounting to approximately 10 degrees Fahrenheit, is implied by the known facts.

Such a decrease in temperature has recurred several times in the history of the earth, but even so it is an unusual condition. Apparently the several ice ages of the past were, each, of comparatively short duration. Each glacial period was separated from the others by much longer intervals during which the climate of the earth was on the whole considerably more genial and equable than it is to-day. In very truth we are still in the shadow of the Great Ice Age. The existing climate is not greatly different from that of the glacial period, whereas during much of earth history the climate has been such as to permit the growth of ferns, corals, figs, and magnolias in

what are now the polar regions. Fossil remains of such plants and animals are found in many rock formations in northern Greenland, Baffin Land, and Antarctica. Such distribution of temperate and tropical plants and animals may be explained either on the basis of a considerable and world-wide increase in temperature, due to the receipt of more heat each year from the sun than the earth is now obtaining, or by a more even distribution of the same amount of heat as that now being received. Probably during much of earth history both of these factors were effective.

Be that as it may, the refrigeration of the earth during the Great Ice Age necessarily involved something more than simply a different distribution of the sun's heat upon the surface of the earth. It means definitely that for some time the earth's surface was receiving everywhere throughout the entire year less warmth than now.

There are two satisfactory lines of approach to this problem. One involves the consideration of changes in the constitution of the earth's atmosphere sufficient to affect its efficiency as the blanket which keeps the surface warm. Snow fields and glaciers exist to-day at high altitudes near the Equator, because the air above the mountain summits is so rarefied as to be comparatively ineffective in the retaining of heat. The most influential of the atmospheric gases, with respect to the retention of heat, is water vapor. When the humidity of the atmosphere is low, its effectiveness as a thermal blanket is slight. But for ice-sheets to form, it is necessary to have both a

low temperature the year round and heavy snowfall. The latter implies comparatively high humidity; therefore the climate of the Great Ice Age cannot be attributed solely to the depletion of water vapor in the air. Again, it is known that unusual quantities of dust in the upper air absorb unusual amounts of heat and cause a chilling of the lower layers of the atmosphere. At times of violent volcanic eruptions, finely pulverized rock is hurled high into the air and the volcanic dust may remain suspended there for some time. It has been suggested that episodes of unusually extensive volcanic activity might thus cause a glacial climate. The appeal to facts, however, rules out this explanation. Volcanic dust is easily recognizable under the microscope and it is not ordinarily found in association with glacial débris. Moreover, the times of excessive volcanic activity in North America have been the times of most genial warmth, as indicated by the fossil plants and insects whose remains are entombed in beds of volcanic ash.

Doubtless there have been fluctuations in the composition of the earth's atmosphere in past ages, but it may well be doubted whether these fluctuations could have been a primary cause in the cooling to a glacial climate. On the other hand, the circulation of the atmosphere and of the oceans has much to do with the distribution of heat upon the surface of the earth, although it has little bearing upon the total amount of heat possessed by the earth's surface as a whole. The localities at which the great ice-sheets of the past were formed were largely de-

termined by atmospheric and oceanic circulation. These were important secondary factors, but not primary causes.

The second line of approach involves a consideration of the amount of heat sent from the sun to the earth during time intervals of the general order of a few thousand years. The changing spots upon the surface of the sun are an expression of the varying intensity of solar energy. It is now fairly well established that the sunspot cycle has a definite relationship to the cycles of climatic change upon the earth. The influence of the sun spots is in part indirect, and the results are in general rather complicated, but they are of the greatest importance. Apparently the interior of the sun is not only a fiery furnace but also a great chemical laboratory. At certain times, large quantities of gas boil up from the inner envelopes of the sun, break through the outermost layers and send fountain-like jets high into space beyond the sun's atmosphere. Doubtless the comparatively trivial changes in solar activity manifest in the changing sun spots may safely be taken as an indication that even greater changes have occurred in the past. During the rare intervals of comparative quiet in the interior of the sun the amount of energy which it sent out into space was decreased. At those times the earth would have received less heat from the sun than normally. Such may have been the Great Ice Ages of the past. Or it may be that the variations in the output of solar energy have had an inverse effect upon earth temperatures. Increased

solar radiation tends to produce increased evaporation from the water surfaces of the earth. This would produce greater cloudiness and heavier precipitation, which in turn would lower the surface temperatures of the earth. The combination of increased precipitation and decreased temperature is exactly that necessary to produce the great ice-sheets.

Again we should recall the fact that there are in space great clouds of very finely pulverized opaque matter, star-dust or planet fragments. The great nebulous region in the vicinity of the constellation Orion is occupied in large part by dark material. Whenever the Solar System passes through such a cloud as this, the specks of matter intervening between earth and sun reduce the amount of heat received by the earth. This is apparently an adequate explanation for the episodes of refrigeration of the earth's surface, although our present ignorance concerning the nature, movement, and distribution of cosmic dust in space makes it impossible to test the theory with precision. The dust clouds of the Orion nebula are directly in the wake of the sun's motion through space. The Solar System was in the locality now occupied by that nebula only about two and one-half million years ago. That interval, however, is very much longer than has ordinarily been computed by geologists for post-glacial time, and it is doubtful therefore whether the Great Ice Age can fairly be ascribed to the passage of the Solar System through the Orion nebula. Unhampered by facts concerning other similar clouds of dust, some of

which may very possibly be even now in close proximity to us, the speculation along such lines seems to be a very satisfactory one.

Thus there is suggested an apparently plausible, though not certainly demonstrated, answer to the query, "what caused the Great Ice Age?" External conditions, either in the sun or in the space between earth and sun, operated to chill slightly the entire atmosphere and surface of the earth. Internal conditions, the circulation of air and ocean water, determined the exact localities at which the world-wide refrigeration should manifest itself in the form of great ice-sheets. To-day we are actually in the waning stages of the Ice Age, and the probability is strong that there will be a slow return during the next few centuries to the genial warmth and more evenly distributed temperatures which have characterized the greater part of the history of Old Mother Earth.

CHAPTER XI

The New England Shoreline

THE dweller by the sea is profoundly impressed with the fact that Old Mother Earth is constantly changing her appearance. Here, as in few other localities, may we see powerful forces, the booming surf and eddying current, altering the landscape overnight. The New England coast is especially interesting to the lover of nature because of the variety and beauty of its scenery, and it intrigues the geologist because along its beaches he can observe the waves and currents vigorously engaged in their task of shaping the land. The craggy headlands of this "stern and rock-bound coast," the ever-changing beaches and bars, the silent marshes with their mysterious past have provided texts for sermons, themes for poems and back-grounds for novels, so that both in song and story the New England shore has an eternal place in American literature. Those who love the sea and wander by the shore are inevitably tempted to seek an explanation for these results of Old Mother Earth's handiwork, for an understanding of the shore phenomena quickens the imagination and deepens the appreciation of the scenic features.

But there are other reasons which to some seem more weighty, for studying such a shoreline as this. The en-

FIGURE 36. The waves beating upon the New England shore are powerful agents of erosion, changing its appearance with comparative rapidity in spite of the resistance of the strong rocks which defend such headlands as this.

gineer interested in coast protection and marsh reclamation can only hope to perform his beneficent task effectively if he understands the natural processes which he must combat or control. "The lawyer knows that not a few legal complications, involving the value of coastal lands and even the title to such lands, may be solved through the study of past changes in the shore, its present peculiarities, and its probable future development."

The New England shoreline is a shoreline of submergence. That is, its major features result from an advance of the sea as this portion of North America was relatively depressed. The sinking of the continent and the extensive flooding of its marginal lowlands were complicated by many oscillations of level; at times the land was elevated so that wave-built beaches were lifted high above the sea and at other times the land stood even lower than it does to-day. Vast ice-sheets have moved across the land and out into the shallow water. When they melted away they left great piles of unconsolidated rock débris which form off-shore islands and jutting capes. Waves and currents have cut back the shore at many places, whereas elsewhere they have built out the land into the sea. The reeds and grasses of bog and marsh have filled lagoons with peaty vegetation, while salt marshes are gradually being transformed into dry land as they are filled with plant remains and dust. The wind has seized the dry sand upon the beaches and piled it into irregular dunes, constantly shifting as the restless breezes play upon them. All these, and perhaps other considerations

should be in mind as one attempts to explain the varied features of this complicated strand.

The eastern part of North America consists of a broad strip of old rocks forming mountains and highlands, bordered on the east by a coastal plain underlain by young rocks in nearly horizontal beds. The oldland includes such rocks as granite, which crystallized from molten lava at some depth below the surface of the earth, and ancient sandstone, limestone and slate which have been intensely squeezed and intricately folded during such mountain-making episodes as that which gave birth to the Appalachian Mountains. The coastal plain consists of a comparatively thin veneer of sedimentary strata which accumulated as layers of mud and sand upon the submerged portion of the oldland. These have never been elevated very high above sea-level and now appear as beds of rock dipping very gently eastward from the oldland toward the Atlantic Ocean basin.

In Georgia and Alabama, the portion of the Atlantic Coastal Plain now exposed above sea-level is 150 to 175 miles wide and its submerged portion, forming the so-called continental shelf beneath the border of the Atlantic Ocean, is only 20 to 40 miles wide. In the Carolinas and Virginia the exposed portion of the plain narrows to 125 miles or less, while the submerged part is 50 to 80 miles broad. In New Jersey, the plain appears to be only 25 to 65 miles wide, but the submerged platform is nearly or quite 100 miles in width. Farther northeastward, narrow fragments only of the Coastal Plain appear in Long

FIGURE 37. Shores composed of unconsolidated glacial débris retreat rapidly before the attack of waves and currents. A portion of this cliff near Scituate, Massachusetts, has been undercut and has slumped downward. The grass-covered surface of the fallen wedge is inclined in the fashion characteristic of most landslides.

Island, Martha's Vineyard and Nantucket, whereas off the coast of Maine it is wholly lost to view. Here, however, the ocean soundings reveal the presence of a submerged shelf more than 150 miles wide. In other words, the real margin of the North American continent is 200 miles southeast of Boston, and the continent is so tilted downward that the coastal plain has entirely disappeared beneath the sea and the waves are now beating against the oldland along the New England shore.

On the exposed portion of the coastal plain south of New York City the characteristic land forms are a direct expression of the structure of the rocks from which the landscape has been carved by brooks and rivers. The more resistant beds of the Coastal Plain series appear in low, inclined table-lands called cuestas. Each cuesta has a very broad gentle slope downward toward the sea, a slope conforming to the upper surface of the slightly tilted layers of rock, and a narrow steep westward face directed toward the oldland, a face or scarp cutting downward from the cap rock of the cuesta to the weaker underlying beds. Between the westernmost cuesta and the higher oldland of the Appalachian region there is an inner lowland from which the young rocks have been removed by the eastward flowing streams.

Similar land forms are now submerged off the New England shore. Long Island is the higher portion of a partly submerged cuesta on which a thick body of glacial drift has been deposited. Long Island Sound is the inner lowland between that cuesta and the oldland

of Connecticut. The Gulf of Maine, that portion of the Atlantic Ocean cut off by a line extended from the tip of Cape Cod to the south end of Nova Scotia, is the inner lowland bordering the oldland of the Maine coast. Platts and Jeffreys Banks, Cashes Ledge and similar elevations on the floor of the Gulf of Maine are cuestas, formerly standing on the coastal plain but now completely submerged. Georges Bank and Brown Bank, east of Cape Cod and south of Nova Scotia, are still larger cuestas with their steep northwestern escarpments rising abruptly from the deeper floor of the Gulf of Maine.

These submarine topographic features must have been sculptured by rivers at a time when New England stood about 1200 feet higher above sea-level than it does today. At that time the largest river between the St. Lawrence and the Hudson had its sources in Maine and flowed eastward in a depression between what is now Georges Bank and Brown Bank before it reached the Atlantic. The resistant rocks of the oldland stood as mountainous heights above the lowland which intervened between them and the cuestas. When the sea advanced to its present position this river was drowned, the cuestas were entirely submerged and many of the hills of the oldland were surrounded to form islands which fringe the ragged coast of Maine.

The greater part of this subsidence of the land must have taken place shortly before or during the Great Ice Age. Changes in level since the glaciers disappeared from New England have been slight in comparison with

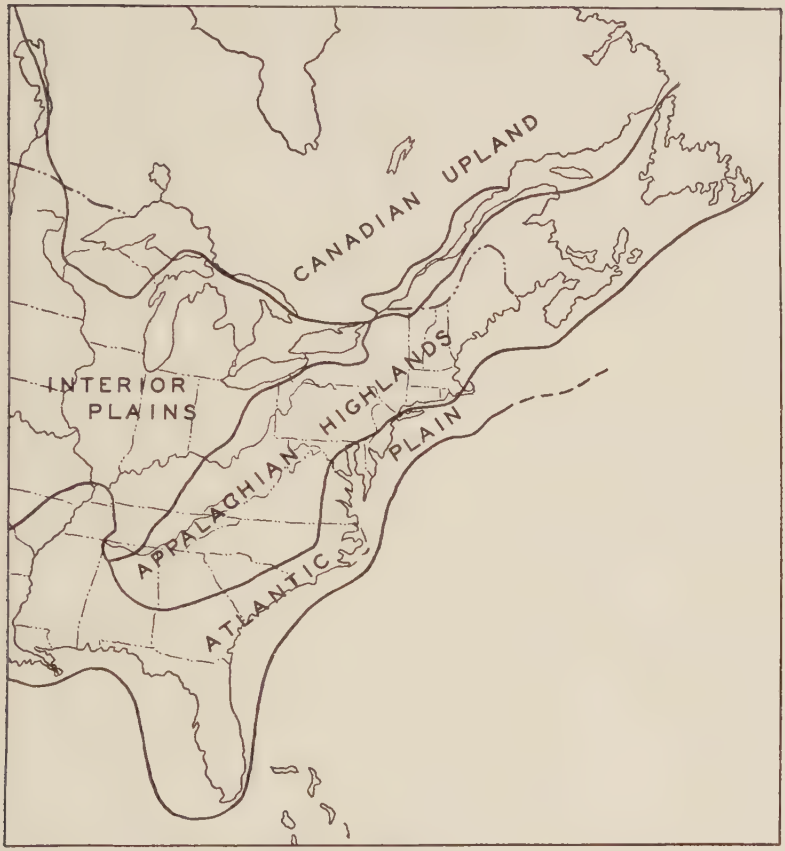


FIGURE 38. From this sketch map of Eastern North America on which the major physiographic regions have been outlined, it may be inferred that the continent is at present tilted downward toward the northeast.

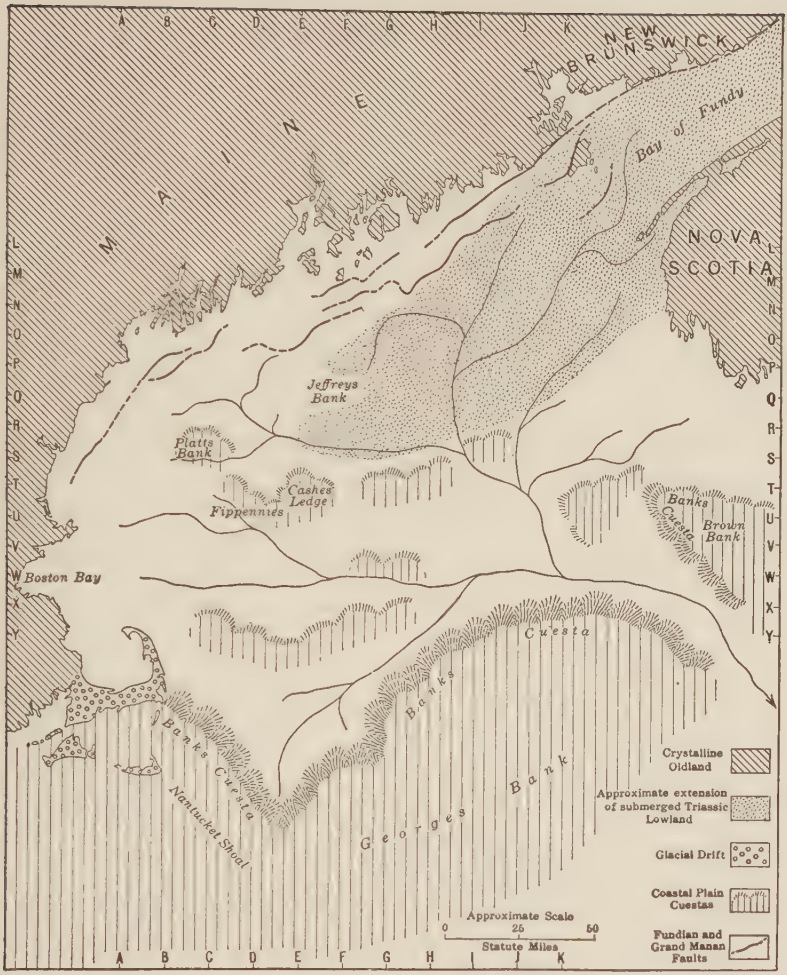


FIGURE 39. On this sketch map of the Gulf of Maine and adjacent areas there are shown the crystalline oldland of a part of New England, the inner lowland of the Gulf of Maine, part of which is floored with Triassic rocks and is therefore called the Triassic Lowland, the submerged cuestas of the coastal plain which form the banks, the hypothetical pre-glacial drainage of the lowland, and the submarine scarps of the Fundian fault zone.

Reproduced from Douglas W. Johnson, The New England-Acadian Shoreline, with permission of John Wiley and Sons, Inc.

those which occurred before the ice had reached its maximum extent. Post-glacial changes are, however, of considerable importance. Beds of clay and bodies of beach sand or gravel, containing the shells of marine mollusks and other sea-dwellers, are now found on top of glacial deposits at various elevations up to 400 feet or more above the sea at certain places in Maine. During the construction of the ship canal across the base of Cape Cod, the roots and stumps of trees which must have grown on the land above the reach of high tide were dredged up from depths of 8 or 10 feet below low tide level. At least 25 feet below sea-level in Long Island Sound near New York City there are beds of clay of the sort that is formed only in fresh-water lakes. Apparently the New England coast has been slightly tilted since the ice melted away, upward north of Boston and downward southwest of Boston.

This post-glacial change of level seems to have resulted from the inter-play of two factors. Apparently the great weight of the ice-sheet caused a sinking of the land on which it rested and this in turn was compensated by an upward bulge of the earth's surface just beyond the margin of the ice. This was complicated by the further fact that the temporary retention of the water on the land in the form of ice decreased the volume of the oceans and lowered sea-level the world around by an amount which is generally estimated to have been between 150 and 200 feet. When the ice melted and the water returned to the sea, its level was universally ele-

vated by that amount. At the same time, the unloading of the land permitted it to return toward the position it had held when the ice-sheets were forming. This would mean that shortly after the ice began to melt away, the land on which it had been resting slowly rose while the surface just beyond the farthest reach of the ice slowly sank. Just north of Boston the uplift of the land was compensated by the rise of sea-level due to return of water to the ocean, but near Portland the land rose 200 feet higher than the new water-level, whereas at Buzzard's Bay the rise of the sea exceeded the uplift of the land and the coast was slightly submerged. Thus the sea came to rest against the land at the present level at a time which is geologically very recent, perhaps only 3000 years ago.

It is still an open question whether relative change of level of the land is going on to-day. If such is the case, the movement must be very slow; certainly there have been no geologically important changes of position in the last few thousand years. The period of human occupation of the coast has been too short and the records too inaccurate to permit the drawing of a definite conclusion concerning crustal movement since man settled here. Changes of only a few inches per century could not be detected except by very accurate surveys, and in all probability that is the rate at which the movements have occurred in the geologic past.

Although the land and sea have thus remained in approximately the same relations for a considerable time,

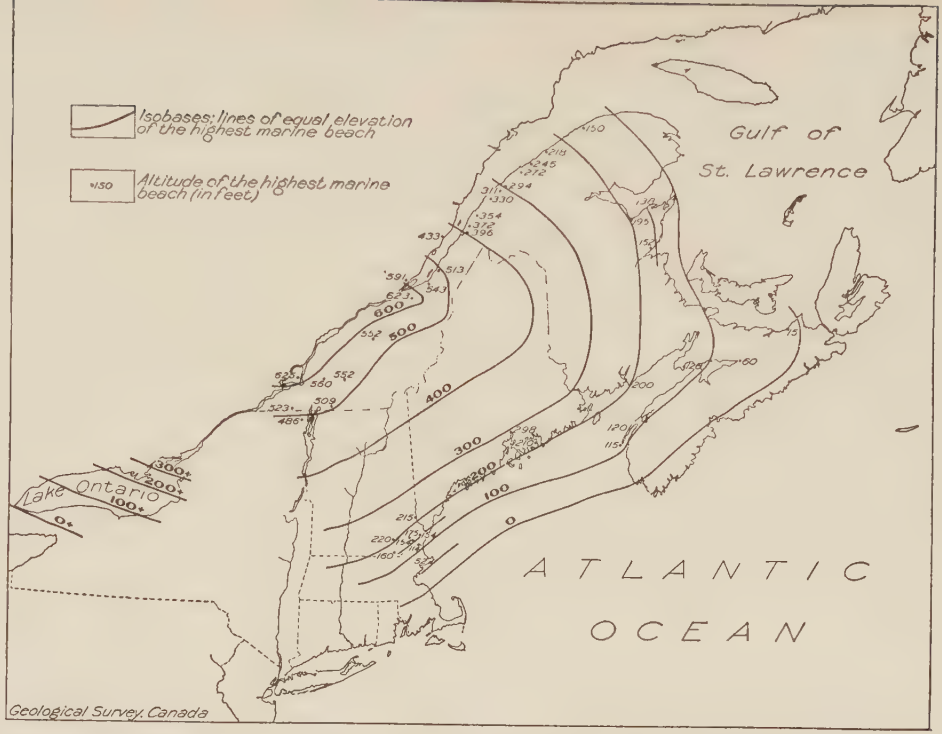

Isobases: lines of equal elevation of the highest marine beach
+150 Altitude of the highest marine beach (in feet)
Gulf of St. Lawrence
ATLANTIC OCEAN
Lake Ontario
Geological Survey, Canada

FIGURE 40. The heavier lines upon this sketch map of New England and the Maritime Provinces show the amount of post-glacial uplift indicated by the present elevations of marine beaches formed as the ice was retreating from this region. All figures indicate altitudes in feet.

From J. W. Goldthwait, Physiography of Nova Scotia, Canada Geological Survey Memoir 140.

there have been many changes in the appearance of the shoreline because of the activity of waves and currents. At many places the shore was formed of glacial débris, heaped irregularly on the rock floor as the ice receded, or spread by the glacial waters in great sheets or deltas beyond the front of the ice. This unconsolidated clay, sand and gravel has yielded quickly when attacked by vigorous waves on exposed shores. Even in Boston Bay the results of wave erosion have been astonishing. Many of the mounds of glacial drift, called drumlins, which originally stood as islands in this bay, have been entirely removed. The Massachusetts Colony Records for September 8, 1636, contain the entry: "There is 12 acres of land granted to John Galop upon Nixes Island to enjoy to him and to his heirs forever." Unfortunately for Galop's heirs the whole island has been completely swept away by the waves, and a bowldery shoal alone marks its former position. Cherry Island Bar, off the Winthrop shore, is another shoal marking the position of a former drumlin known as Cherry Island, now completely destroyed by the waves, although in the early days of the Massachusetts Colony it was used as a pasture for cows. Winthrop Head is another drumlin undergoing wave erosion; the cliff cut in its seaward face receded 36 feet in the 48 years between 1860 and 1908, an average of 9 inches per year.

Between Highland Light and Nauset Lights, the outer coast of Cape Cod is a wave-cut cliff, 50 to 140 feet high, exposed to the main waves of the Atlantic. The material

is glacial drift, a moraine left by the great ice-sheet, and the gravel, sand and clay washed out from the ice as it melted. The remarkably simple pattern of the regular shoreline along the outer side of the fore-arm of the Cape has been developed by the waves. A few thousand years ago they were beating against an irregular shore, two or three miles east of the present strand line. This cliff is retreating at the unusually rapid rate of more than 3 feet per year, for it is subjected to the full force of the Atlantic storm waves. At this rate the narrower parts of Cape Cod will be cut through in a little more than 3000 years from now. Presumably, elaborate coast defenses will be necessary to retard wave erosion and preserve the Cape for human occupation.

Much of the material removed by the waves from the seaward side of Cape Cod has been deposited by the longshore currents in the complex recurved spit at Provincetown. At many other places along the New England shore the changes effected by waves and currents have been similarly constructive. Some of the islands formed when the land was submerged to its present relations with the sea have subsequently been tied to the mainland by long low bars of sand. Duxbury Bay is now partially enclosed by Duxbury Beach and Saquish Neck, wave-built forms which unite the former islands of Gurnet Point and Saquish Head to the Massachusetts coast near Plymouth. Nahant and Little Nahant were formerly islands, and they too have been connected with the mainland by a wave-built neck known as Lynn Beach.

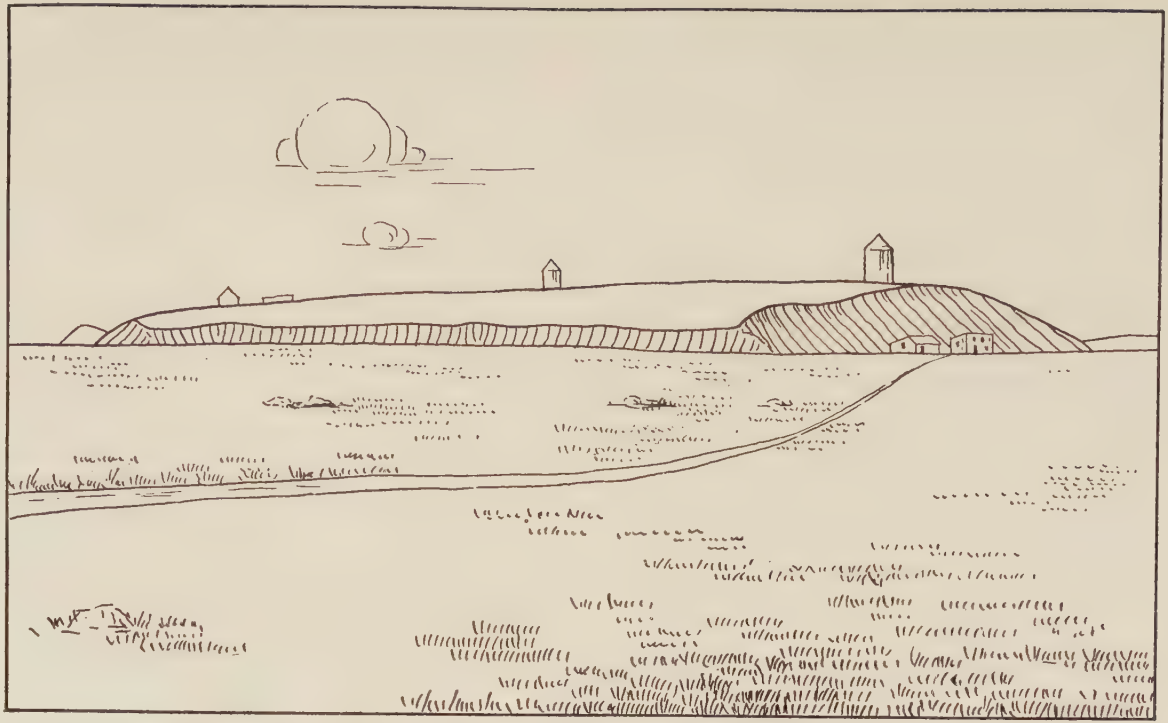


FIGURE 41. Strawberry Hill, near Nantasket, Massachusetts, is a drumlin which has been cliffed on all sides by the waves of the Atlantic. The material removed from this and adjacent drumlins was deposited during the construction of Nantasket Beach and the cliffs are no longer exposed to the sea.

Sketch by Edward A. Schmitz from photograph by Douglas W. Johnson.

An unusually interesting record of shoreline changes is found in the wave-cut cliffs and beach ridges of Nantasket Beach. Originally this part of Boston Bay was occupied by a number of small round islands, each a drumlin left by the ice. Among these were Telegraph Hill, Great Hill at Allerton, and Strawberry Hill which now overlooks Nantasket Beach. As soon as the sea advanced to its present position, the waves attacked the shores of these islands. Some of them were entirely destroyed and are known now as shallow ledges beneath the waters of the bay, east of Nantasket. Others were partly cut away and now display steep cliffs on their eastern sides; Sagamore Head, at Surfside and the east face of Strawberry Hill are good illustrations of such wave-cut cliffs. While their erosion was progressing, the material removed from the cliffs was in part deposited as bars between the islands. Some of these bars were built above the average water-level and thereby the directions of the currents were changed. In the lee of Great Hill, Nantasket Beach was constructed with its gracefully curving shore passing in front of Strawberry Hill which is now completely protected from wave erosion, except on its west side. The beach is now at approximately the greatest size which Old Mother Earth could probably give it. Until very recently it has been increasing in area; in the future, the normal development of this shore line will result in decreasing its area, as Great Hill is worn away and its protection removed. This is in fact the key to the preservation of the entire Nantasket

Beach district. The sea-wall recently constructed for the preservation of Little Hill at Allerton also gives protection to the adjacent areas of Great Hill. By such protective measures man may indefinitely postpone the normal changes which nature would effect in the Nantasket area. Knowing how Old Mother Earth is going about her task of changing the appearance of this shore, man may either coöperate with her to hasten the changes or interpose defences which will help to maintain the existing land forms. At Nantasket, he has chosen to do the latter.

FIGURE 42. When the waves and currents began the construction of Nantasket Beach, southeast of Boston, Massachusetts, there were a dozen drumlins forming islands in the sea. Quarter Ledge (Q), Allerton Little Hill (L), Allerton Lost Drumlin (AL), Bayside Lost Drumlin (BL), Strawberry Lost Drumlin (SL), White Head Lost Drumlin (WL), Atlantic Lost Drumlin (AtL), and Skull Head (Sk) have since been nearly or quite completely destroyed. Thornbush Hill at Hull (T), Nantasket or Telegraph Hill (N), Hog Island (LHi), Allerton Great Hill (G), Strawberry Hill (St), Bunkin Island (Bi), White Head (W), Sagamore Head (Sa) and Hampton Hill (H) still retain something of their original form.

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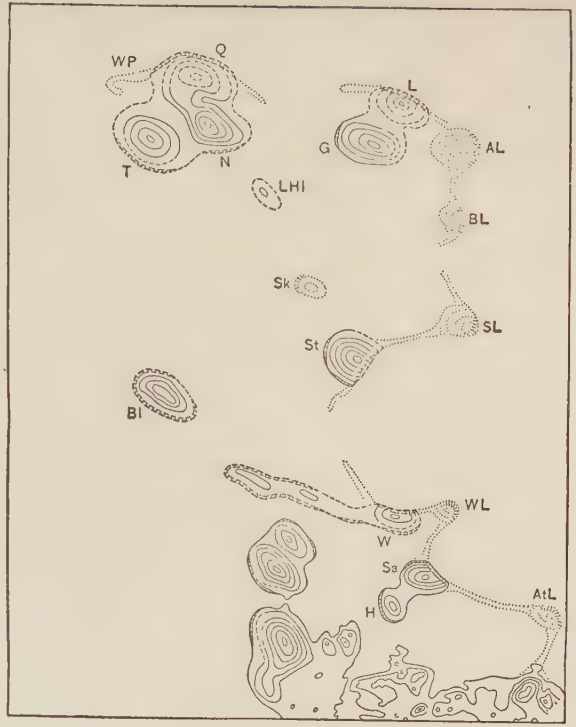


FIGURE 43. A later stage in the development of Nantasket Beach was marked by the cliffing of the drumlins and the construction of bars and spits.

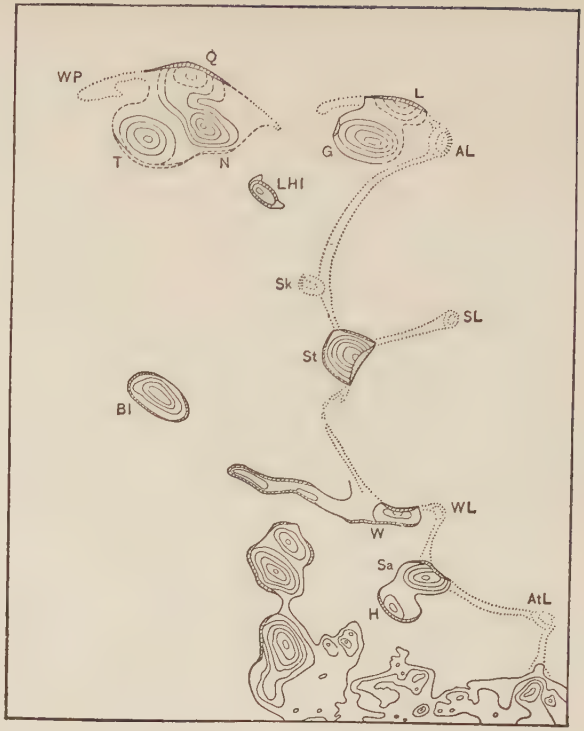


FIGURE 44. Still later the bars were extended until certain of the drumlins were tied together by low beaches.

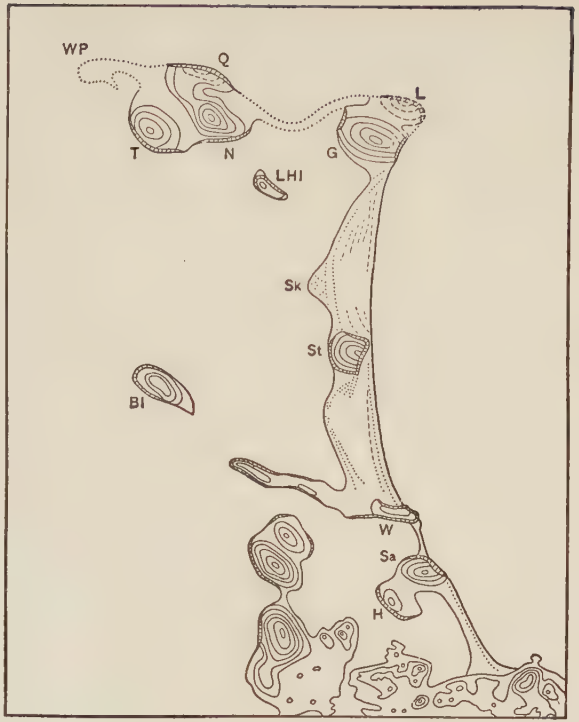


FIGURE 45. As time went on, the more exposed drumlins were entirely removed and Nantasket Beach began to assume its present form.

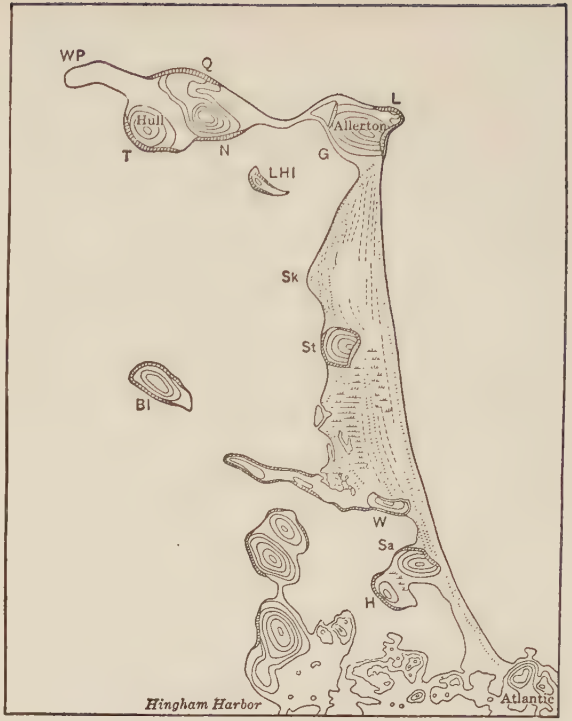


FIGURE 46. Only minor modifications were needed to produce the present form of Nantasket Beach from that shown in the preceding figure.

CHAPTER XII

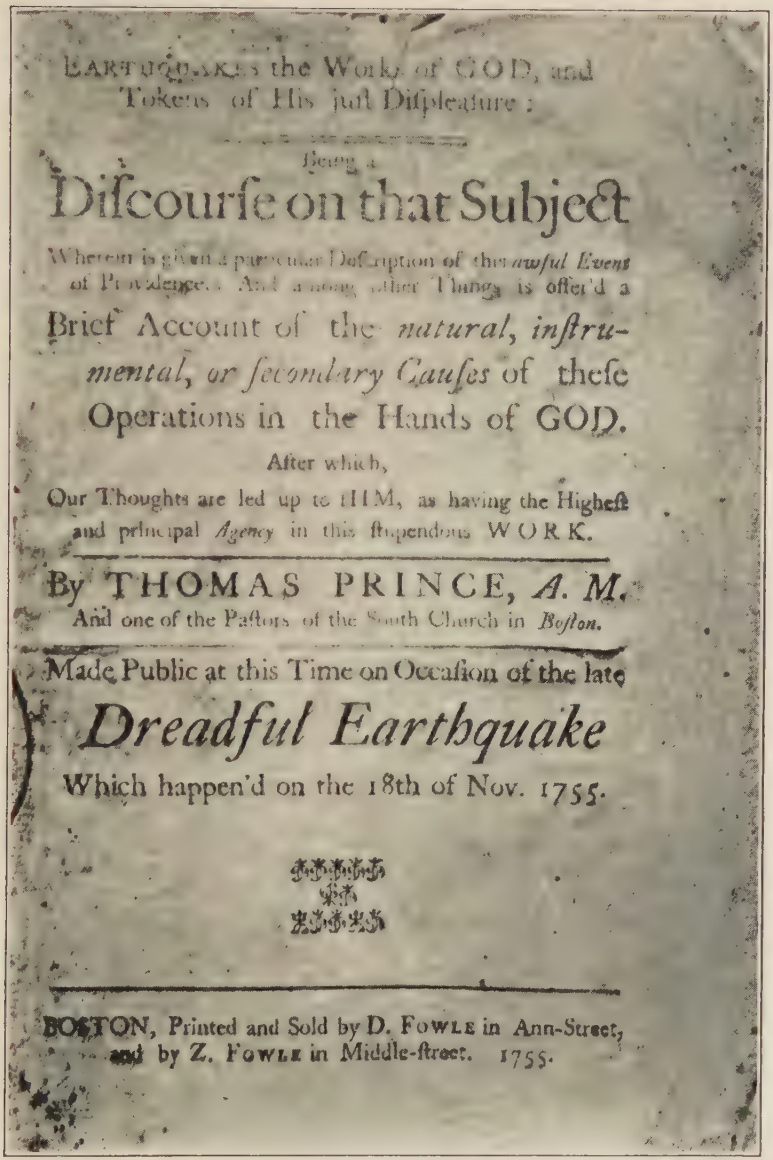
Earthquakes

JUST about the time that the Pilgrim fathers were beginning to have a sense of security in the new land which they were endeavoring to settle, they were subjected to an experience just as new as their contact with "Red Indians" and in many respects more startling. Bradford's History of the Plymouth Colony contains the following record: "This year (1638) about the first or second of June was a great and fearful earthquake. The earth began to shake and came at length with that violence as caused platters, dishes and such like things as stoode upon shelves, to clatter and fall down; yea, persons were afraid of the houses themselves. It was very terrible for the time, and as the men were set talking in the house, some women and others were without the doors, and the earth shooke with that violence as they could not stand without catching hould of the posts and pails that stood next them. It was not only on the sea-coast, but the Indeans felt it within land; and some ships that were upon the coast were shaken by it. So powerful is the mighty hand of the Lord, as to make both the earth and sea to shake, and the mountains to tremble before him when he pleases; and who can stay his hand?"

On February 5, 1663, the entire northeastern part of North America was shaken by an earthquake which

from contemporary accounts seems to have been the most violent ever recorded on this continent. The centre of the disturbance was in the St. Lawrence Valley where buildings were destroyed and the ground broken open. The vibrations were so severe that even at so distant a place as the shore of Massachusetts Bay, "houses were shaken so that pewter fell from the shelves and the tops of several chimneys were broken." For a time the church authorities and the French Government seriously considered the abandonment of the entire project of colonizing and Christianizing the St. Lawrence region because of the fear that a land subject to such quakes would forever prove unsatisfactory for human abode.

Nearly a century later, on November 18, 1755, there occurred the so-called "great Boston earthquake," a tremor which was felt from Chesapeake Bay to Nova Scotia and westward to the Hudson Valley. Considerable damage was done in Boston. "Besides the throwing down of glass, pewter, and other movables in the houses, many chimneys were levelled with the roofs of the houses, and many more shattered and thrown down in part. The roofs of some houses were quite broken in by the fall of chimneys; and the gable ends of some brick buildings thrown down, and many were cracked. In some places, especially on the low, loose ground made by encroachments on the harbor, the streets were almost covered with the bricks that had fallen." So far as known, there was no loss of life and few injuries, due in


EARTHQUAKES the Works of GOD, and Tokens of His just Displeasure:

Being a

Discourse on that Subject

Wherein is given a particular Description of the *awful Events* of Providence. And among other Things is offer'd a

Brief Account of the *natural, instrumental, or secondary Causes* of these Operations in the Hands of GOD.

After which,

Our Thoughts are led up to HIM, as having the Highest and principal *Agency* in this stupendous WORK.

By THOMAS PRINCE, *A. M.*

And one of the Pastors of the South Church in *Boston.*

Made Public at this Time on Occasion of the late

Dreadful Earthquake

Which happen'd on the 18th of Nov. 1755.

BOSTON, Printed and Sold by D. FOWLE in Ann-Street, and by Z. FOWLE in Middle-street. 1755.

FIGURE 47. This photograph of the cover of a sermon pamphlet published in Boston in 1755 indicates the reaction of the ministers of that day to the "Great Boston Earthquake."

large part to the fact that the quake came a few minutes past four in the morning when the streets were quite deserted. No shock of intensity comparable to this earthquake of 1755 has since occurred in southern New England except possibly the East Haddam, Connecticut, quake of May 18, 1791.

The scene shifts to the southern Mississippi Valley, where in the winter of 1811–1812 occurred a series of earthquakes of such intensity that only the comparatively uninhabited condition of the region prevented a great disaster. New Madrid was then a trading post on the Mississippi River, 60 miles south of the mouth of the Ohio. In 1811 it had grown to be a considerable settlement, with a population greater than that of any other town in Missouri except St. Louis. Shocks began on December 16, 1811, and continued at intervals for several months. According to the reports of eyewitnesses the whole land was moved and in continual agitation like the waves of the sea, shaking so violently that persons were thrown off their feet and the forest trees were crashed to the ground. Great fissures appeared in the earth, some of them 600 to 700 feet in length and 20 to 30 feet in width. Large sections of the river banks caved into the stream bed, carrying houses and cattle with them, but fortunately the human inhabitants seem to have all escaped in safety. Again on February 7, 1812, at 4 A.M., there was a tremor which has gone down in local history as "the hard shock." It was so severe that as far away as St. Louis, crockery fell from shelves and in

Cincinnati buildings were slightly damaged. The New Madrid earthquake was felt as far northward and eastward as Detroit, Washington and Boston. All told, an area of nearly two million square miles was so disturbed that the tremors were felt by a large percentage of the population, a record equalled by no subsequent earthquake in North America.

The Charleston, South Carolina, quake of August 31, 1886, was felt over a slightly smaller area, but caused much greater loss of life and property because its centre happened to be near a large city in which building construction had not been planned with any thought of the possibility of earth tremors. Scores of houses in Charleston were demolished and scarcely a building in the entire city escaped damage. The scientific study of earthquakes in the United States may be said to have begun with Captain Dutton's examination of the nature and effects of that earthquake and the report which he made to the United States Geological Survey.

Seismology, the science of earthquakes, received another important impetus in 1906, when on April 19 the city of San Francisco was involved in a disastrous quake. Men no longer looked upon such catastrophes as an evidence of Divine wrath or as punishment sent from God because of immoral conduct. As perfectly natural phenomena, earthquakes must be studied, their habits learned, their causes discovered. Only thus may man safeguard himself against unnecessary loss of life and property.

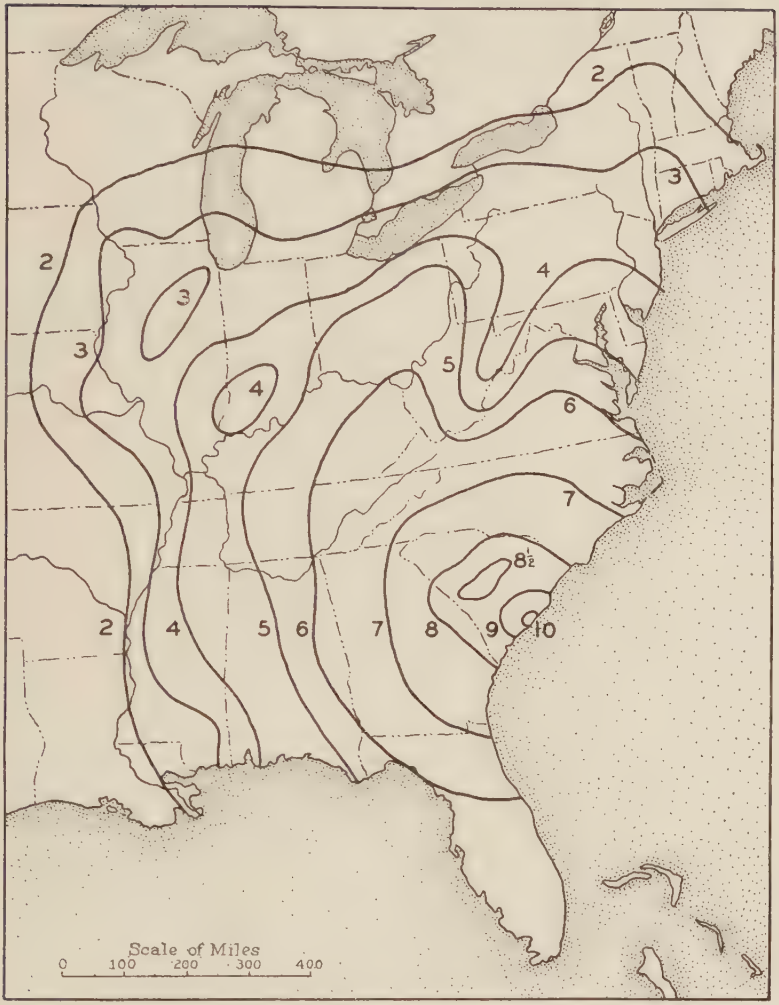


FIGURE 48. An isoseismal map is constructed by drawing lines through the points on the earth's surface at which a particular earthquake displayed equal intensities. Thus, on the map representing the Charleston earthquake of 1886, the line numbered 7 surrounds the area in which that earthquake displayed an intensity on the Rossi-Forel scale of 7 or greater, while outside of that line the intensity was less than 7, and similarly for each unit on the scale. Within the small circle numbered 10, that earthquake was of maximum intensity. The series of concentric lines records the decrease in intensity with distance from the place of origin.

Sufficient records are now available to indicate that earthquakes originate at some point or a series of points beneath the earth's surface. From the place of origin, vibrations spread outward through the body of the earth in all directions. In the solid rocks the seismic waves involve a to-and-fro motion of the rock particles of only a small fraction of an inch, but in the loose material at the earth's surface, or in buildings free to sway, the vibrations are greatly amplified. Directly above the place of origin or centrum of an earthquake, loose objects are hurled vertically upward, as though struck a terrific blow from underneath by a gigantic hammer. Such a place on the earth's surface is called the epicentrum and there the damage is likely to be at a maximum. Some distance away from the epicentrum the blow resulting from the transmission of the swiftly advancing wave or tremor is obliquely upward, and bricks may be snapped out of chimneys and thrown laterally at a velocity equal to that imparted by gravity. As the earthquake wave travels outward from the point of origin, it is like the ripples on a placid pool when a pebble is tossed into the water. Gradually the waves decrease in height and finally they die. Even the world's most severe earthquakes cease to be of damaging intensity at distances of only a few score miles from the epicentrum; rarely are they felt at distances beyond a few hundred miles from their place of origin. They may, however, actually travel clear around the earth and have frequently been recorded on seismographs thousands of miles distant. A seis-

mograph is a piece of apparatus especially designed to detect and record the vibrations of the ground. Seismograph records enable the expert to tell something of the actual intensity of the quake and to estimate the distance the waves have travelled from the place of origin to the recording station. As soon as the distance from three stations is known, the place of origin, frequently beneath the sea, can be determined.

Earthquake waves travel at varying velocities, depending upon their nature and the elasticity of the rocks traversed. Most of the waves move at velocities between $2\frac{1}{2}$ and 7 miles per second. Thus the Japanese earthquake of 1923 began to be recorded on the seismograph at Harvard University 14 minutes after that quake struck Tokyo, and the last of the vibrations did not reach Cambridge until over an hour later. The Santa Barbara earthquake of June 29, 1925, was recorded at Harvard $7\frac{1}{2}$ minutes after the quake actually occurred in that California city.

Such vibrations may be originated in several ways. They are akin to the results of explosions or of sudden blows of a hammer. Some are caused by volcanic eruptions, but the most damaging ones have resulted from the sudden slipping of the rocks within a few miles of the earth's surface along a fracture, broken when the crust of the earth yields to strain. When the rocks of the earth's crust are folded into mountain chains like the Appalachians the several beds may bend and slip past each other like the pages of a magazine when rolled in

FIGURE 49. At some places along the San Andreas Rift the movement which caused the San Francisco earthquake involved a vertical uplift of 2 to 4 feet.

one's hand. If so, the sliding of the beds involves a series of sudden jars, as friction is overcome and movement occurs. Each jar may give rise to an earthquake. Or the crumpling of the earth's crust may involve the fracturing of the rocks along planes which divide it into great blocks like cakes of ice in an ice-floe. These slide and grind past each other in the attempt to ease the strain which has accumulated at the particular place, and again the earthquake vibrations are started. The fracture planes are called faults by the geologist. They may be discovered by the fact that commonly rocks of one kind or one age abut directly against rocks of another kind or another age on the other side of the fault. Actual movement of the fault blocks has been observed in connection with many of the earthquakes in California. Where the movement involves the surface of the ground, the term earthquake rift is applied to the crack or fracture zone which appears there. Thus the San Andreas rift passes a few miles to the west of San Francisco and has been traced for more than 200 miles along the California coast. At the time of the San Francisco earthquake the ground on one side of this rift moved horizontally past that on the other side. Roads and fences which crossed the fault line were broken and offset five to twenty feet. The San Andreas fault was an old one along which in earlier geologic periods there had been much greater movement. Undoubtedly there will be additional slipping along it in future centuries.

Strains within the earth which cause such movements

are themselves caused in several ways, not all of which are clearly understood at present. Shrinkage of the earth due to compacting or cooling of its interior must involve the wrinkling of its outer shell, just as the skin of an apple wrinkles if the fruit is dried in the sun. Transfer of load from land to sea-floor as rivers wear away the hills and build deltas at their mouths puts every coastal region in a condition of stress. Melting away of the great ice-sheets has recently taken a heavy burden from the northern lands. These and other causes involve the slow accumulation of strain. Finally, the last straw breaks the camel's back; the resistance of the earth's crust is overcome; somewhere an adjustment takes place. As the rocks bend or slip, they ease the burden and temporarily relieve the strain. Then a long interval must elapse before a new strain accumulates to the breaking point. That is why destructive earthquakes at any one place are separated by scores of years of comparative quiet. Thus it will probably be twenty or thirty years more before a renewal of movement along the San Andreas rift should be expected. This also explains why earthquakes are frequently grouped together so that brief periods of unusual seismic activity have recurred at long intervals. When the strain is relieved at one place it may thereby be increased at some other locality and thus most of the great earthquakes are followed by many "after-shocks" before stability is attained.

For example, the earthquake record for New England

FIGURE 50. The San Andreas Rift crossed this road at right angles and the horizontal displacement at this locality in 1906 caused the offset which appears just beyond the wooden culvert.

indicates that about 350 shocks have been felt in this region between 1627 and the middle of 1927. The average number of earthquakes throughout the period of occupation of New England by white men is thus indicated as $1\frac{1}{6}$ tremors per year; but the distribution is very uneven and shows a definite grouping of earth disturbances within certain decades. In the eleven years from 1727 to 1737 inclusive, 65 earthquakes are recorded. Again in the thirteen years from 1843 to 1855 inclusive, there were 56 recorded vibrations. Another interval of unusually abundant seismic activity seems to have begun late in 1924, as at least 21 earthquakes have been noticed since September of that year. Of the New England earthquakes, the great majority were of such slight intensity as to occasion no more than brief alarm on the part of startled individuals. Probably something more than 40 of the number were sufficiently violent to damage fragile articles in dwelling houses located in close proximity to the point of earthquake origin and to cause panic under such conditions as exist in our densely populated cities. At least a dozen were of sufficient violence to have caused considerable loss of property and great danger to life at the places of greatest vibration, had those places been situated within the limits of a city like modern Boston. Fortunately, the majority of the cities in New England and the eastern states in general are situated at least a few miles away from the places at which earthquakes are most likely to originate. Shocks of moderate intensity may startle their inhabitants, but catas-

trophes like that at Tokyo and Yokohama in 1923 are not likely to occur here.

With few exceptions earthquakes are dangerous chiefly because adequate precautions are not taken to guard life and property against their effects. The history of even the greatest earthquake catastrophes clearly indicates that mistakes made by men before or during the disaster largely increased the toll. The wise community profits by its own experience and by that of other communities. An overwhelmingly large percentage of the damage due to earthquakes is preventable. Building for security in time of earthquake is reasonably practicable and economical, except in the case of extremely severe shocks such as rarely occur, even in localities of high seismicity like California and Japan. The obligation to protect the community rests largely with engineers, architects, contractors, insurance men and property owners. Information concerning the geographic distribution, historical sequence and effects of earthquakes is now available. Unfortunately, here as elsewhere, human knowledge of what ought to be done is far in advance of human practice.

FIGURE 51. The wreckage of the Hotel Californian at Santa Barbara, California, caused by the earthquake of June 29, 1925, shows the characteristic 45° cracks which result from the horizontal vibration of the ground. Much of this damage could have been prevented by proper methods of construction which would have tied the walls and joists together so that they would vibrate as a unit.

CHAPTER XIII

The Earthquake Hazard in New England

SINCE the earthquake of February 28, 1925, which was felt generally throughout New England, questions have frequently been asked concerning the possibilities of future earthquakes. Will one or more of the prosperous cities in New England suffer the same fate which befell San Francisco in 1906, Tokyo and Yokohama in 1923, Santa Barbara in 1925, or is this part of North America immune from quakes of destructive intensity? Such questions are obviously of the greatest importance, and an attempt should be made to answer them as honestly and completely as possible.

Unfortunately the study of earthquakes has not yet provided a scientific basis for specific predictions concerning the place, time and intensity of future tremors. Although the nature and immediate causes of earthquakes are now fairly well understood, it is not yet possible to measure the accumulating strains within the earth so as to discover in advance the date and locality at which the strains will be eased by movements of the earth's crust. It is simple enough for an expert to predict that there will be an earthquake in Japan in the latter part of February, and his prediction will be

made good, because on the average four earthquakes occur every day in that country. Most of these are only trivial, but earthquakes of sufficient intensity to damage property have occurred in Japan on an average of two per month during the last few centuries. Such predictions are obviously of no value whatsoever. To be of value the prediction must tell the exact locality and date of the disturbance. It may be that within a few years predictions of that sort will be made possible, but much remains to be learned concerning earthquakes and the condition of the earth's interior before that sort of prediction can be made.

On the other hand, it is now possible to determine with a fair degree of accuracy the earthquake expectancy or hazard for any locality. The distinction between earthquake prediction and earthquake expectancy is not always understood. The life insurance companies can tell a man at any time how long he may expect to live; they cannot predict when he will die. Expectation of life is based on compilations of records of the past; so is expectancy of earthquakes. An individual's expected span of life can be inferred, with a very wide margin for error, by observation of his present physical condition; similarly the earthquake expectancy of a region may also be inferred by examination of its geologic structure. In considering the earthquake hazard in New England attention must first be paid to the record of past earthquakes in this locality. Then its geologic structure must be examined to discover if possible the nature and inten-

sity of the strains accumulating within the earth and the places at which those strains are most likely to be relieved. The third factor in determining earthquake hazard is the human element and concerns the nature and location of buildings, water mains and other structures made by man as well as the mental traits of the inhabitants of the area.

It is unlikely that an entirely accurate and complete list of New England earthquakes can ever be obtained, although town histories, newspaper files and other sources have been searched for records from which to compile a list of those felt by man in this locality. Many earthquakes have not been recorded in such histories because people have sometimes had the erroneous idea that the best thing to do about them is to forget them as promptly as possible. However, records of nearly 350 earthquakes felt in New England since 1627 are now at hand. This figure is conservative because it counts as single earthquakes several groups of tremors which occurred within a few hours of each other on a single day. The great majority of these vibrations were very trivial and quite local. More important than the entire number of earthquakes is the number of tremors which had sufficient intensity to cause damage to property or frighten severely the inhabitants of a particular place. Such episodes would scarcely escape the chronicles and the record is probably fairly complete for them.

In considering them it is necessary to use some sort of scale to indicate the differing intensities of the individual

shocks. The standard scale for this purpose is known as the Rossi-Forel scale of earthquake intensity. According to it, earthquakes are grouped in ten classes numbered from I, the least intense, to X, the most destructive. Intensity V on the Rossi-Forel scale indicates a shock of moderate intensity, felt generally by everyone, which causes doors and windows to rattle, disturbs furniture and rings swinging bells. Intensity VII indicates a strong shock which causes general panic, overthrows movable objects, causes plaster to fall from ceilings, but does not damage buildings seriously. Intensity X is a great disaster in which buildings are totally ruined, many lives are lost and fissures appear in the ground.

During the past three centuries, seventy-one earthquakes having intensity V or greater on the Rossi-Forel scale have been felt in New England. These may be grouped into two classes on the basis of area affected. The commoner kind is typified by the Cape Ann earthquake of January 7, 1925 and the southern New Hampshire earthquake of October 9, 1925. In each of these the area throughout which the earthquake was felt totalled less than 10,000 square miles and the area within which the quake could have caused more than momentary and passing alarm was less than 150 square miles. Such earthquakes originate within a few miles of the surface of the earth and their energy is concentrated in a small area at points close to their origin. They may cause considerable damage, as the intensity might be locally as great as VII or VIII on the Rossi-Forel scale,

TABLE III

ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

I. Microseismic shock: recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. Extremely feeble shock: recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. Very feeble shock: felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. Feeble shock: felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.

V. Shock of moderate intensity; felt generally by everyone; disturbance of furniture, beds, etc.; ringing of swinging bells.

VI. Fairly strong shock: general awakening of those asleep; general ringing of swinging bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. Strong shock: overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. Very strong shock: fall of chimneys; cracks in walls of buildings.

IX. Extremely strong shock: partial or total destruction of some buildings.

X. Shock of extreme intensity: great disaster, buildings ruined; disturbance of the strata, fissures in the ground, rock-falls from mountains.

but, fortunately, most if not all of such earthquakes which have occurred in historic time in New England were so situated that the area of greatest violence was at least a few miles distant from any large city. Most of them have had their centres either in regions of strong crystalline rock like that of southern New Hampshire or beneath the sea just off the coast of Maine, New Hampshire and Massachusetts. Such localized quakes have recurred at irregular intervals. Often they have been grouped in definite series in such a way that five or ten earthquakes were felt in a period of a few years and then many years would elapse without record of any earthquake whatsoever.

A few of the earthquakes which have shaken New England belong in quite a different category, of which the quake of February 28, 1925 is typical. Such earthquakes are felt over areas totalling hundreds of thousands of square miles and are of sufficient intensity to cause considerable damage throughout areas aggregating several thousand square miles. The fact that the maximum intensity of such shocks is not much greater than the maximum intensity of those of the type just described leads to the belief that they originate at points much deeper beneath the surface of the earth. A city like Boston, if situated within a hundred miles of the place on the earth's surface directly above the point of origin of such an earthquake, would suffer material damage from it.

Earthquakes of this second group are fortunately few

and far between. They include the Quebec earthquake of February 5, 1663, the St. Lawrence earthquake of September 16, 1732, the Boston earthquake of November 18, 1755, the Charleston earthquake of August 31, 1886, as well as the Quebec earthquake of February 28, 1925. High intensities were reached near the points of origin of these quakes, and intensities of VII or VIII on the Rossi-Forel scale were developed 100 or 200 miles away.

The study of earthquakes in all parts of the world indicates that sometimes, but not always, groups of earthquakes occurring in a district in a brief sequence of years, consist of fore-shocks, a relieving shock, and after-shocks. If the series is complete, there is no difficulty in distinguishing the several parts of the sequence. The fore-shocks are moderately severe and limited in their effects to a small area. The relieving shock is one of great intensity and large area. The after-shocks gradually diminish in intensity and frequency. Thus the San Francisco earthquake of 1906 was a relieving shock for northern California. So far as the Santa Barbara earthquake of June, 1925, is concerned, it is not now known definitely to what extent it may have relieved or increased strains in southern California. The Quebec earthquake of February 28, 1925, was presumably of the type which relieves the strain throughout a considerable area. Unfortunately, there is at present no way of telling whether that earthquake relieved the strain beneath the whole of New England as well as beneath the St. Lawrence Valley. It

is possible that the failure of the earth's crust in the St. Lawrence Valley has increased the strain beneath southern New England. If so, we may expect renewed activity soon. Under such conditions it is a wise policy to prepare for the worst and hope for the best.

To ascertain what is the worst shock that might be expected at any particular place one must examine into the geologic structure of the area. Such a study of New England does much to allay our fears concerning future earthquakes.

The geologic condition of the Atlantic seaboard is in striking contrast to that of the lands bordering on the Pacific Ocean. This explains the difference in earthquake frequency and earthquake violence between the two sides of the continent. The mountain rim of the Pacific Ocean was subjected in comparatively recent geologic time to very intense crustal movement which elevated portions of the land many thousands of feet above adjacent portions of the sea-floor. Great fracture planes, or faults, may be traced along the front of many mountain ranges in California. Movements of the broken blocks of the earth's crust along these fracture planes have totalled scores of miles in the last three or four geologic periods. Moreover, accurate measurements indicate that displacement along certain of the California fault planes is taking place at the present time. Such faults are aptly referred to as "alive."

In contrast, the mountains of New England and the eastern states in general are without exception exceed-

ingly old. The crumpling of the earth's crust along the eastern side of the continent was accomplished in very remote geologic time. In and near the city of Boston there are scores of faults along which the earth's crust was ruptured. Displacement of the broken fragments amounted to many thousands of feet. Some of the blocks were moved upward and others were moved laterally. But all this happened so long ago, and evidence of recent activity of these fault planes is so completely lacking that geologists have looked upon them as "dead."

One of the major fault planes of North America separates the rocks of the Laurentian Upland, north of the St. Lawrence River, from the rocks which underlie the flat St. Lawrence Valley between Montreal and the sea. This is a very ancient plane of crustal movement and no observations have been reported which indicate that this fault is now "alive." It is, nevertheless, viewed with suspicion because of the continent-shaking earthquakes which have originated near it on several occasions. It is highly desirable that several monuments be accurately located by precise surveys in this area, some on one side and some on the other side of the fault zone. Re-surveys twenty or fifty years hence would tell whether or not this supposedly "dead" fault is now undergoing movement.

The Connecticut Valley is, in large part, underlain by a wedge of younger rocks faulted down into contact with very much older rocks and broken into a mosaic of shattered fragments. The major faults which outline the sides of the wedge trend northward from Connecticut

across Massachusetts on either side of the Connecticut Valley. Crustal movement here must also have occurred at a very remote date in the geologic history of the continent. No facts are known which directly indicate that the faults in the Connecticut Valley, like those of the California coast, are now "alive." They must, however, be viewed with suspicion, for a large number of slight earthquakes have originated in their vicinity. Precise surveys in that area ought also to be made, and monuments should be located with reference to the major fault planes, so that slight movements of the land may be detected if they are now going on. Signs of "life" displayed by a "dead" fault would in many cases be detected in advance of serious break, if sufficiently precise surveys were made every few years.

Along the northern coast of the Bay of Fundy there is an ancient geologic fault which trends southwestward and disappears beneath the waters of that bay. A long line of cliffs submerged beneath the Gulf of Maine is believed to represent the southwestward extension of that so-called "Fundian fault" and marks its position a few miles off the Maine shore. This line of cliffs continues nearly but not quite to Cape Ann. The fact that many of the earthquakes which have shaken parts of New England in the last three centuries had their origins in fairly close proximity to these submerged cliffs leads to the suggestion that the Fundian fault is now subject to slight movements. It is therefore possible that this fault should be classed as "alive." Any considerable

movement along it would cause an earthquake of more than moderate intensity at Boston. So far as earthquakes of limited extent are concerned, it is likely that the Fundian fault is the most important danger zone for this city.

Combining the data gathered from the history of earthquakes in New England with those supplied by the geologist's knowledge of the earth's structure in this part of the continent, the conclusion is valid that an earthquake in Boston of greater intensity than VIII on the Rossi-Forel scale is highly improbable. On the other hand, an earthquake of intensity VII or VIII may occur here at any time. Earthquakes of that severity were felt in Boston in 1638, 1663, 1727, 1744 and 1755 but no shock exceeding intensity V has affected the city since the eighteenth century. Evidently the intervals between destructive earthquakes are to be measured in scores of years. They may belong to either of the two classes previously noted. A local but fairly intense shock may centre very near the city, or a widespread "relieving shock" may jar the whole of southern New England.

As pointed out by Professor Woodworth in the seventh annual report of the Harvard Seismographic Station, issued in 1916, the "long intervals of repose and minimum seismic activity lull suspicions and cause the multitude to regard what has not occurred in their father's and grandfather's days as a possibility too remote to enter into their own lives. Nevertheless it behooves us to remember that the earthquake at Plymouth, Massachu-

setts, in 1638, at Newbury, in 1727, at Boston in 1744 and more strikingly in 1755, and yet more impressively at Charleston, South Carolina, in 1886, and at San Francisco in 1906, offer phenomena during more than three centuries, the time of occupation of the middle latitudes of the North American continent by European peoples, of the magnitude of the local play of the seismic force. It is evident that the intervals between epochs of great destructive force in the same locality are to be measured in centuries and fractions of a century. Until science shall have discovered the signs of the return of these alarming and often disastrous earthquakes, we can only bear in mind that as we recede in the steady march of time from the epoch of one of these events, we draw nearer, step by step, to the next one in the series."

The earthquake which shook Boston in 1755 is a fair indication of the maximum intensity of earth vibrations which are likely to affect this area during the next few hundred years. If this city, or any other city in New England, should plan its life and structures with reference to the possible recurrence of the 1755 Boston quake it will have done all that can reasonably be expected of the community in the attempt to safeguard itself against loss of life and property from earthquakes. That earthquake damaged several hundred buildings, but, so far as known, no building was completely destroyed nor was there any loss of life. This, however, does not mean that Boston would be similarly spared if this type of shock should recur in 1930. Boston to-day is very much more

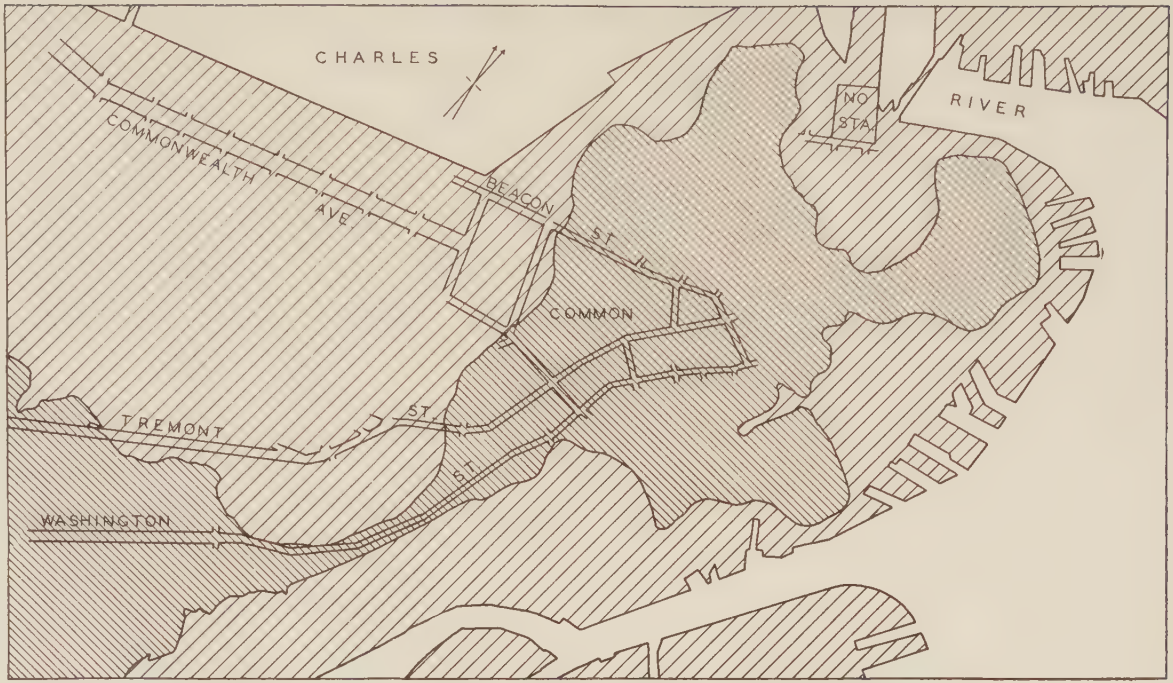


FIGURE 52. This map of the heart of Boston shows in dark shading the original outline of the peninsula and in lighter shading the "made ground" on which the city has been expanded to its present area.

susceptible to serious damage and loss of life from earthquakes than it was a century and a half ago. Much of the city is now constructed on made ground. The accompanying map showing the original and the present shore lines of the district speaks for itself. It is true that in the area reclaimed from sea and fen there are many buildings on foundations which go down through the fill to firm ground, and these buildings are just as secure with respect to earthquake as though they were situated on Beacon Hill. Unfortunately, however, there are many blocks of poorly constructed buildings into which the population is closely crowded. Hundreds of buildings have been constructed in the last fifty years without any reference whatsoever to earthquake impact and upon foundations literally floating on soft muck and fill.

The difference in effect of earthquake vibrations upon structures situated on reclaimed marsh land as compared with those located on firm terrane was clearly indicated by the earthquake of February 28, 1925. In a number of buildings in the Back Bay region that earthquake displayed intensity of IV or V, while only a few hundred yards away in other parts of the city where houses rest on compact glacial drift or firm bed rock, the earthquake passed quite unnoticed, as its intensity there was only II or III. Similarly in the city of Quebec the harbor works on soft alluvium along the St. Lawrence River were seriously damaged, while residents of the so-called "Upper Town" were quite unaware that an earthquake was taking place.

Well-constructed buildings situated on compact bowlder-clay or solid rock are not liable to serious damage during an earthquake of intensity VII or VIII. In modern concrete and steel construction the various parts of a building are ordinarily so securely tied together that the entire building vibrates as a unit and emerges unharmed. But any building, the foundations of which are in soft material, sand, clay or fill, must be carefully designed and securely cross-braced to make it safe. Earthquake vibrations are multiplied three to ten times, so far as their tendency to damage buildings is concerned, when they pass from solid rock into water-soaked fill such as that used in reclaiming marshes and tidal flats. Obviously, building codes such as are now in effect in certain California cities should be made to apply to those portions of New England cities which overlie the less stable ground. If this is done promptly, in a few decades the existing blocks of poorly constructed, ram-shackle buildings will have been replaced by structures which are practically earthquake proof.

Fully as important as a stricter building code is the provision for more extended scientific research. If up-to-date seismograph stations could be established, properly coördinated and operated for a few years, at a dozen somewhat widely separated localities from northern Maine to Connecticut, it is extremely probable that much of the present uncertainty as to time, place, and intensity of future earthquakes could be replaced by definite

knowledge. This is one of the most important of the few fields of research which have not been extensively endowed by public-spirited individuals. It is an opportunity seldom equalled for real and lasting service to humanity.

Because of the intense and unreasoning fear which earthquakes commonly engender in the minds of those who are startled by their first experience of the kind, panic is a grave danger accompanying even a slight quake, should it occur at a time when large crowds are assembled in department stores, churches, schools or theatres. Rushing wildly for the street is the most foolish procedure possible. The safest place during any earthquake which is likely to be experienced in New England is a doorway between rooms in the interior of a building, or an inner corner of a room. Old Mother Earth is challenging man in New England. In some parts of the world the earthquake hazard is such that the contest is hopeless; man is in the grip of forces too powerful for him to combat. But that is not the case here. The earthquake hazard in this region is such that if the emergency is met with true foresight and proper plans, the loss from any earthquake which may reasonably be expected will be reduced to an almost negligible minimum. Better building regulations should be enforced in those localities which are known to be particularly unstable. Safety measures in respect to public utilities like gas, oil and electricity, should be devised. Relief organizations

TABLE IV

LIST OF EARTHQUAKES OF EPICENTRAL INTENSITY OF VII OR MORE, WHICH HAVE BEEN FELT IN NEW ENGLAND

Year	Day	Hour and Minute	Epicenter	Intensity (Rossi-Forel Scale)		Appreciably shaken area
				At Epicenter	At Boston	
1638	June 11[1]	2.00–4.00 P.M.	Off Cape Ann	VIII	VII	"All New England"
1663	Feb. 5[2]	5.00–6.00 P.M.	St. Lawrence Valley	X	VII	Entire eastern part of North America
1665	Mar. 6[3]		Quebec	VIII	II	Northeastern N. America
1727	Nov. 8[4]	11.00, 11.40, 11.45 P.M.	Off Cape Ann	IX	VII	Maine, Virginia, Pennsylvania
1732	Sept. 16[5]	11.00 A.M.	Quebec	IX	III	New England and Eastern Canada
1737	Dec. 18[6]	10.30–11.00 P.M.	Near New York?	VIII	IV	Records inadequate
1744	June 14[7]	10.00 A.M.	Off Cape Ann	VIII	VII	Southern New England
1755	Nov. 18	4.11 A.M.	Off shore east of Boston	IX	VIII	Halifax to South Carolina to Great Lakes

1791	May 16	8.00 A.M.	Near East Haddam, Conn.	VIII		Southwestern New England
1791	May 18	10.00 P.M.	Near East Haddam, Conn.	IX	III	Boston to Philadelphia
1857	Dec. 23	1.30 P.M.	Near Lewiston, Maine	VII		Southern Maine
1860	Oct. 17	6.00 A.M.	St. Lawrence Valley	VIII	II	Quebec to New Jersey
1869	Oct. 22	6.00 A.M.	Bay of Fundy	VIII	II	New England and Maritime Provinces
1870	Oct. 20	11.25 A.M.	St. Lawrence Valley	IX	III	New Brunswick to Iowa and Virginia
1886	Aug. 31	9.50 P.M.	Charleston, S. C.	X	II	Eastern United States
1893	Nov. 27	11.50 A.M.	St. Lawrence Valley	VII	III	Quebec, New England, New York
1904	Mar. 21	1.04 A.M.	Near Eastport, Maine	VII	IV	New England and Maritime Provinces
1918	Aug. 20	11.20 P.M.	Near Norway, Maine	VII		Southwestern Maine
1924	Sept. 30	3.50 A.M.	Western New Brunswick	VII		Quebec, New Brunswick, and Northern Maine
1925	Feb. 28	9.19 P.M.	Near Murray Bay, Quebec	IX	V	From Canada south to Virginia and west to Illinois

[1] June 1, Old Style. [2] Jan. 26 (1662), Old Style. [3] Feb. 24, Old Style. [4] Oct. 28, Old Style. [5] Sept. 5, Old Style.
[6] Dec. 7, Old Style. [7] June 3, Old Style.

should be prepared for the particular kinds of work which experience in California and Japan indicates is necessary. The public in general should be instructed in the amenities of conduct during earthquakes. Facing the facts open-eyed, one can see no cause for alarm; there is every reason for wise preparation.

CHAPTER XIV

How Mountains Are Made

"The hills are shadows, and they flow
From form to form, and nothing stands;
They melt like mist, the solid lands,
Like clouds they shape themselves and go."

ALTHOUGH Tennyson was not a geologist, he clearly recognized certain fundamental geologic principles. From time immemorial, agents of erosion have been sculpturing the surface of the earth, wearing down the mountains and casting them into the sea. Erosion effected by the running water of brooks and rivers, the wear of glaciers, the attack of restless winds, combine eventually to smooth the surface of the earth and bring it to an even grade. Uplands are worn away and lowland basins occupied by lakes or oceans receive the débris as sediment. If these forces of gradation had been permitted to operate undisturbed and unopposed the continents would long since have disappeared. The solid crust of the earth would ere this have been enveloped by a universal ocean.

Impressed as the geologist is by the efficiency of the agents of erosion and by the long eons of time during which these agents have been at work, it becomes immediately apparent that there must be other forces which tend to renew the inequalities of the earth's sur-

face. Opposed to the forces of gradation are certain constructive processes which at some places build high mountains and at others form deep ocean abysses. These non-gradational processes are constantly competing with the agents of erosion. The form of the land at any place is a result of the inter-action between the two kinds of geologic processes.

The most obvious of the processes which construct high mountains or build broad plateaus are those connected with the activity of volcanoes. Many of the lofty mountains of the earth's surface are volcanic cones, constructed of lava poured forth to congeal upon the sides of the growing volcano or of masses of pulverized rock, volcanic ash and similar débris hurled violently into the air during an explosive eruption. Where volcanic eruptions are long continued or recur again and again throughout successive geologic periods, the piles of ejected materials may be constructed to lofty heights. Thus Fujiyama, the Sacred Mountain of Japan, appears to-day as a beautiful, symmetrical cone the summit of which is mantled with perpetual snow although its base is approximately at sea level in a temperate latitude. Mount Shasta and Mount Rainier are excellent examples of volcanic cones of huge dimensions. In each of them the volcanic fires are now extinct. Upon their slopes, rivers and glaciers have carved rugged valleys which greatly modify the form of the mountain sides so that no longer are they such symmetrical cones as once they must have been. Many of the most rugged mountains of the west-

Photograph by Vittorio Sella.

FIGURE 53. Gas and steam are constantly escaping from the crater on the summit of Mt. Etna and at occasional intervals bombs and ashes are ejected upon the upper slopes of this great volcanic cone.

ern states have similarly been sculptured from great volcanic plateaus in which the successive lava flows and layers of volcanic débris total many thousands of feet in thickness.

Still other mountains were formed by the crystallization of molten lava in fissures or chambers beneath the surface of the earth. At certain localities, the lava rising toward the surface has spread out like a mushroom to form a thick lens above which the rocks are lifted in a broad arch. Such lens-shaped masses of rock, crystallized from molten lava, are known as laccoliths, and the mountains which they make are laccolithic mountains. The classical example is the group of hills in southeastern Utah known as the Henry Mountains. In that locality there formerly was a thick series of flat layers of sandstone, shale and limestone. Into these horizontal beds the molten lava was intruded from the deeper interior of the earth. As it rose it found at one level an opportunity to spread laterally. The higher beds of rock were arched upward and the surface was lifted to a height of about 3000 feet above its surroundings. From this great mound the existing mountains have been eroded by wind and water. The rocks which crystallized from the molten state are very resistant to erosion, and consequently they persist in the rugged peaks at the centre of the mountain group. Around their flanks appear the remnants of the arched cover, layers of sandstone and shale which dip downward from the mountains and then flatten out beneath the surrounding plateau.

The Black Hills of South Dakota have a somewhat similar domal shape but cover a much greater area. The central parts of the Black Hills consist of rocks which for the most part crystallized from molten lava deep beneath the surface of the earth. Similarly, the margins of this mountain group display tilted beds of sandstone and limestone which dip downward away from the crest of the hills. This dome, however, was not formed by the intrusion of molten lava but must have been arched by a vertical up-thrust from beneath the surface. The crystalline rocks in the centre of the hills are much older than the sedimentary rocks which surround them and were present as the floor of the basin in which the sandstone, limestone and shale were long ago accumulated as sediment. Therefore, the Black Hills cannot be considered as laccolithic mountains, but may rather be classified as mountains of vertical uplift.

Very precise determinations of the force of gravitation reveal the fact that the rocks which compose and underlie such elevations as the Black Hills are appreciably lighter in weight than the rocks beneath adjacent lowlands. In general, the higher the mountain or plateau, the lower is the specific gravity of the block of the earth's crust of which it is formed; the lower the plain or basin, the higher is the specific gravity. This relationship extends to the large segments of the earth's shell, for the rocks beneath the oceans are notably heavier per cubic mile than the rocks which form the continents. From these facts it is inferred that the outer portion of the

FIGURE 54. Sliding glaciers and restless rivers have slightly sculptured the slopes of Mt. Rainier but it still retains much of the original shape of a symmetrical volcanic cone.

earth is in a condition of more or less perfect isostatic adjustment. Isostasy is a term derived from the Greek words meaning "equal pressure." It is believed that all blocks of the earth's crust press downward equally upon the deeper portion of the earth's interior. Thus the column of rock beneath Pike's Peak, although a mile and a half taller than the column beneath Denver, has the same weight because it consists of somewhat lighter materials than its neighbor. Indeed, the principle of isostasy would imply that Pike's Peak stands at its great elevation because the underlying materials are light and the earth column must be tall in order to balance the adjacent shorter columns of heavier substances.

This principle implies further that somewhere beneath the outermost shell of the earth there is material which acts as if it were plastic, even though we know that the earth as a whole is essentially solid. Presumably this potentially plastic material yields very slowly to long-continued stresses. In consequence the various blocks of the earth's crust are for all practical purposes floating upon a plastic substratum. The facts concerning local variations in the force of gravitation seem to indicate that the differences in density of the various portions of the outermost shell of the earth are all compensated at a depth of about sixty miles, but no reliance can be placed upon the accuracy of that figure.

When mountains suffer erosion, the weight of that particular column of rock is decreased. The eroded material is deposited in an adjacent basin or upon the margin

of the continent and weight is thus added to other rock columns. The outermost shell of the earth is strong enough and rigid enough to withstand considerable strain but eventually the unloaded column becomes so light and the loaded columns become so heavy that vertical movements take place. The lightened column rises and the mountain is re-elevated, whereas the weighted columns sink and the partially filled basins are deepened anew. In consequence the agents of erosion must continue their never-ending task, because ever and again the inequalities of the earth's surface are renewed.

The principle of isostasy also explains the fact that almost without exception no deep-sea deposits have ever been found upon the surface of continents. "Once an ocean basin, always an ocean basin; once a continent, always a continent," seems to be the rule. The marine sediments which form the sedimentary rocks, so widespread on every continent, are sand and mud which accumulated in shallow seas resulting from the flooding of the lowest parts of the continents. Hudson Bay is today typical of the seas which overspread the continents. Its sediments are marine but are not in a true ocean basin. They are shallow-sea, rather than deep-sea deposits.

Layers of rock, obviously formed of sand grains or mud particles washed into a body of water, and containing the fossil shells of animals that inhabited just such seas as Hudson Bay, are now found at elevations of many thousands of feet above sea level. I have myself collected fossil shells of salt water bivalves, belonging to species

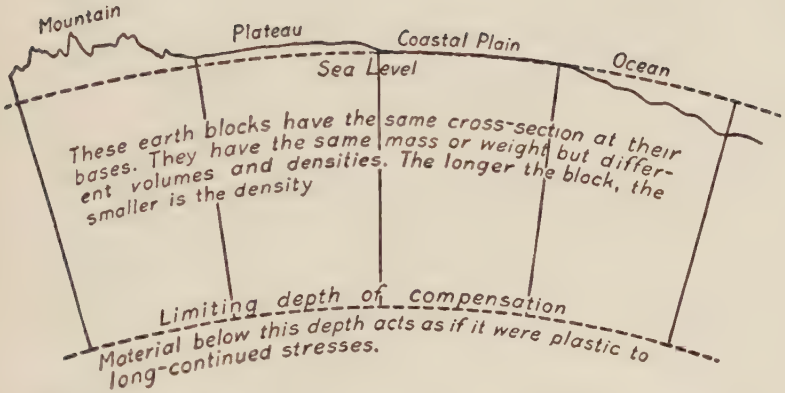

Mountain
Plateau
Coastal Plain
Ocean
Sea Level
These earth blocks have the same cross-section at their bases. They have the same mass or weight but different volumes and densities. The longer the block, the smaller is the density
Limiting depth of compensation
Material below this depth acts as if it were plastic to long-continued stresses.

FIGURE 55. According to the principle of isostasy represented in this diagrammatic cross-section of the crust of the earth, the altitude of the surface is proportional to the density of the underlying rocks.

From William Bowie, Isostasy, with permission of E. P. Dutton & Co.

now extinct but closely related to modern clams, at elevations of 13,000 feet in the San Juan Mountains in Southern Colorado, as well as fossil remains of other marine organisms at elevations of more than 14,000 feet in the Andes of Bolivia. These figures are by no means the maximum, but give a fair indication of the magnitude of the vertical movements which have occurred during the geologic history of the earth. Such elevation of ancient shallow basins also indicates that other factors than those directly involved in isostatic adjustment have been operative during the history of Old Mother Earth.

Many of the long and comparatively narrow mountain ranges like the Appalachians, the Southern Rocky Mountains and the Alps consist of portions of the earth's crust which have been wrinkled or crumpled into long narrow folds. Some years ago in Eastern Bolivia, I explored the Front Ranges of the Andes and found them to consist of long steep-sided ridges standing one or two thousand feet above flat lowlands. Each ridge was a huge wrinkle in the earth's crust. Layers of sedimentary rocks were there folded upward into the type of structure known to geologists as an anticline. On each side of each anticline the rock layers dip steeply downward away from the summit of the fold. One of these wrinkles was traced for 170 miles from north to south and had a width of only three or four miles from east to west. In some of the canyons which crossed that mountain range the entire arch was exposed on the canyon wall, but in many other

mountain ranges somewhat similar anticlinal arches have been so deeply eroded that the sedimentary rocks appear only on the sides of the mountains while the ancient crystalline rocks which form the basement floor beneath the sediments are exposed along the middle of the range.

The Colorado Front Range, a part of the Southern Rocky Mountains, is of this type. Pike's Peak is a sculptured portion of the uplifted basement complex. In the Garden of the Gods and elsewhere along the eastern foot of the range, the overlying sedimentary rocks may be seen dipping steeply downward to disappear beneath the Great Plains. These inclined beds are the eastern limb of the huge arch. Formerly they extended, thousands of feet in thickness, high above the summit of Pike's Peak, but that was long ago and the greater part of these strata have been carried away by wind and stream, leaving only the remnants along either flank of the mountains.

Folds of this nature are too sharp to be explained on the basis of vertical movement alone. Such movement may warp the crust into broad gentle flexures, but it cannot make tightly compressed folds. These structures are the result of lateral pressure which squeezes the rocks horizontally. Caught as between the jaws of a closing vise, the layers of rock are crumpled into corrugated folds or are broken and overthrust, one portion upon the other — anything to reduce the area and relieve the strain of compression. In the making of the Appalachian Mountains,

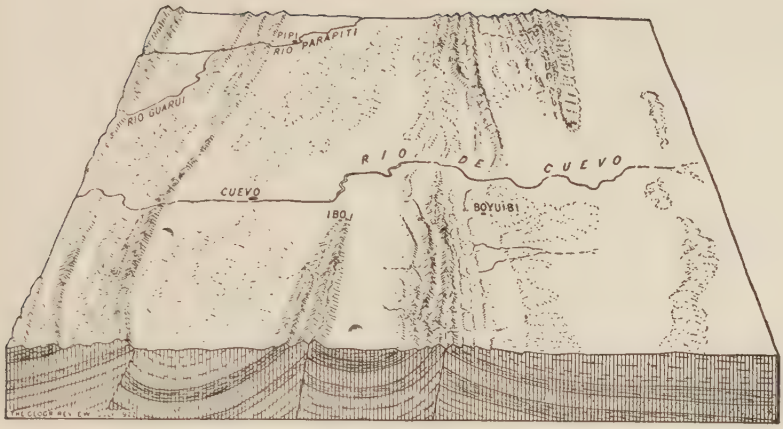


FIGURE 56. On this block-diagram are represented the surface features and geologic structure of a portion of the Front Ranges of the Andes Mountains in eastern Bolivia. Contraction of this part of the earth's crust is clearly indicated by the relations and attitude of the beds of rock which form the long narrow ridges.

a strip of the earth's surface nearly 500 miles in width was compressed to a width of less than 300 miles. Similarly, the overturned folds in the Alps indicate that a portion of Southern Europe which was formerly more than 400 miles in width has been squeezed until it was reduced to a width of less than 200 miles.

Such wrinkling of the crust under lateral pressure has at many places changed shallow basins, undergoing progressive sinking as the weight of deposited sediment increased, into mountains high enough above their surroundings to attract the agents of erosion. As the higher portions of the new-made mountains were removed, the weight of that segment of the earth's crust was reduced, and after a time there occurred vertical uplift in accordance with the principle of isostasy. Many mountain ranges show this sequence. Subsequent to an episode of crustal crumpling, there have been repeated episodes of vertical uplift by which the elevation has been renewed whenever erosion proceeded far toward bevelling down the corrugations of the landscape. As erosion thus proceeds, the weaker rocks yield more readily than the more resistant ones. In consequence, in most of the ancient mountain ranges the harder rocks form the highest elevations regardless of whether or not they were originally lifted to the greatest heights when the region was first crumpled.

The most puzzling problems concerning the making of mountains are those connected with the forces of lateral compression or horizontal movement. Geologists at this

time are deeply interested in discovering just what these forces are, and how they operate. Considerable differences of opinion exist between different students of this problem, because not enough facts are known to permit the drawing of definite conclusions at several critical points.

Two different kinds of forces may be considered: internal and external, those which cause the earth as a whole to contract and those which tend to make the outer shell of the earth, or fragments of that shell, slide laterally over the deeper interior. If the earth as a whole shrinks to a smaller volume, its outer shell must wrinkle to fit the dwindling interior. An apple left standing in the sun soon displays a wrinkled skin because of loss of volume due to evaporation of its internal moisture. If the earth's radius is reduced by one mile, its circumference is decreased by a little more than six miles. A decrease in radius of two or three hundred miles would easily explain all the known mountain structures of the earth's surface. But this cannot be due, as was formerly supposed, to loss of heat. The rate at which the earth is losing its internal heat is so slow that in a hundred million years its radius would be decreased less than a mile in consequence of contraction caused by cooling; it may, however, be due to physical and chemical reorganization of the materials in the interior of the earth where temperatures and pressures of extraordinary degree are developed. Such processes are very slow, but would result in increased density and therefore decreased volume as time goes on.

FIGURE 57. The spires and ridges in the Garden of the Gods consist of nearly vertical beds of sandstone which were tilted into this position when the Front Range of the Colorado Rocky Mountains was folded upward. The crest of the huge arch has been eroded away, but these beds on the eastern flanks of the fold indicate something of its structure.

On the other hand, there are certain external forces, due to the rotation of the earth and its relations to the moon, which tend to pull the outer crust of the earth westward and equatorward. These are believed by some to be competent to move the continents laterally and make them slide or drift upon the plastic subsurface material. Thus it is suggested that the Americas have drifted westward away from Europe and Africa. As they moved, the forward edge of the two continents was crumpled upward to form the Pacific Mountain System of North America and the Andes of South America. A quantitative examination of these forces indicates serious doubt as to their ability to do the tremendous amount of work involved in making such mountain ranges. They may be competent to cause the continents to drift, provided the resistance to such movement is not very great. But if the resistance is slight, there can be no such crumpling of strong rocks along the front margin of the advancing continent. We are therefore left very much in the dark concerning the real causes of the lateral compression displayed in the folded mountain systems. Nevertheless, much is known about the geologic past of many mountains, some of which have had a long and complicated history. Here, as elsewhere, knowledge and mystery exist side by side. We may not understand the full nature of the forces involved in the making of mountains, but we can discover the effects which these forces have produced. Perhaps when the effects are sufficiently well known, the nature of their causes may be fully comprehended.

CHAPTER XV

The Making of the Appalachian Mountains

THE Appalachian Mountain system includes the highest, roughest, best watered, most densely forested lands east of the Mississippi River. Its topography and natural resources have exerted a most profound influence upon the history of mankind in this part of the continent. This influence is a result of the geologic factors which have made the mountain system what it is to-day. Although knowledge of how the Appalachian Mountains were made cannot change the relations between man and his environment, it is nevertheless obvious that such knowledge can guide mankind in many ways toward the wisest utilization of the resources in this region. It is, therefore, with the thought of its practical value as well as because of its academic interest that the geologist turns to this important chapter in the history of Old Mother Earth.

The Appalachian region extends for 2000 miles northeastward from Alabama across New England, Acadia, and Newfoundland. Part of this territory is submerged beneath the sea in the Gulf of Maine, the Bay of Fundy, and Gulf of St. Lawrence. At the northeastern shore of Newfoundland the Appalachian region disappears be-

neath the Atlantic Ocean where its rocks are buried not only beneath the water but also beneath a veneer of sand and mud spread upon the ocean floor, and even now gradually consolidating into the youngest of sedimentary rocks. Similarly at the southwest, the Appalachian type of rocks disappears beneath the younger sedimentary strata of the Coastal Plain in Alabama and Georgia. At one time, long after the Appalachian Mountains were made, the Gulf of Mexico extended over this Coastal Plain, and its waters were in the same relation to that end of the mountains that those of the Gulf of St. Lawrence bear to Newfoundland to-day.

The Appalachian system has a width varying from less than 80 miles to more than 270 miles. It is widest near its southern end, in Tennessee, Georgia, and the Carolinas, and again near its northern end in Quebec, Maine, and New Brunswick. From New York City northeastward the eastern margin of the Appalachian region is the Atlantic shore-line. Southeastward from New York City this margin is the inner border of the Atlantic Coastal Plain, which at many places is approximately the ancient Atlantic shore-line in that region. Beneath the Coastal Plain the Appalachian rocks are buried beneath flat-lying beds of sandstone, shale, and limestone, or unconsolidated layers of gravel, sand, and mud, most of which were deposited in the shallow portion of the Atlantic Ocean at a time when the land stood appreciably lower than it does to-day.

In the Appalachian region there are two distinct types

of mountains which may conveniently be called the Older Appalachians and the Newer Appalachians. The former is the higher and more rugged of the two. At the south, in northeastern Alabama, easternmost Tennessee, and the Carolinas, the Older Appalachians include the Unaka Mountains, the Great Smoky Mountains, and the Blue Ridge. Among the many peaks with summits at elevations greater than 5000 feet is Mount Mitchell, the highest point in the eastern half of the United States, standing 6711 feet above the sea. Northeastward from North Carolina the Older Appalachians decrease both in height and in width. In contrast to the confused mass of irregular and disordered ridges and peaks of the Unakas and the Great Smoky Mountains, the Blue Ridge stretches across Virginia and into Maryland as a single straight, narrow, rather smooth-crested barrier.

Much farther northward the Older Appalachians again include a broad region of lofty and spectacular mountains, among which the Green Mountains of Vermont and the White Mountains of New Hampshire are best known. In the White Mountains the most important feature is the Presidential Range with its several summits having altitudes of more than 5000 feet. Among these, the highest is Mount Washington, 6290 feet in elevation, the nearest New England rival of Mount Mitchell.

Throughout most of its length the Older Appalachian system is bordered toward the Atlantic by a maturely dissected plateau. In the southern states this is the Piedmont Plateau, with its many elevations standing a few

FIGURE 58. The relief map of Pennsylvania displays clearly the contrast between the Newer Appalachian Mountains, with their long narrow ridges which curve across the state or run in zig-zag patterns, and the Appalachian Plateaus in which the valleys are quite irregular because the flat strata exert little or no influence upon the drainage pattern.

hundred feet above tide and separated by fertile valleys which are in general very much broader than the narrow ravines and gulches in the mountains themselves. East of the White Mountains in New England is a very similar undulating plateau, but it stands at a much lower level so that portions of it are actually submerged beneath the Gulf of Maine.

Paralleling the Older Appalachians on the west and northwest, there is a wholly distinct and very different mountain system, the Newer Appalachians. These consist of long, narrow, even-crested ridges rising to elevations of one or two thousand feet above broad, flat-floored valleys. For many miles the valleys and the ridges trend closely parallel to each other and to the longer axis of the entire Appalachian system. In and near eastern Pennsylvania, however, the ridges have a zigzag pattern and many of the valleys are canoe-shaped. Nothing exactly comparable to these ridges of the Newer Appalachians is observable in New England or eastern Canada, although somewhat similar rocks continue northward in the Hudson Valley and Champlain Trough. In sharp contrast to the granite, marble, slate, and similar rocks of the Older Appalachians, the ridges and valleys of the newer system consist of sandstone, limestone, and shale.

The western margin of the Newer Appalachians is bordered at the south by the Cumberland Plateau, in and near Pennsylvania by the Allegheny Plateau, and in New York State by the Catskill Mountains. All of these con-

sist of comparatively flat-lying beds of the same sort of rocks as those in the Newer Appalachians.

With this general description in mind, it is possible to relate the geologic story of the making of this mountain system. Throughout the Paleozoic Era, the third of the five great eras into which the recorded geologic history of the earth is customarily divided, the area now occupied by the Older Appalachians was almost continuously a land mass, whereas the area of the Newer Appalachians was repeatedly submerged beneath the sea. A broad, shallow trough extended northeastward from Alabama into New England. Erosion of the Older Appalachian lands supplied a great quantity of sand and mud, which was washed into the shallow sea that flooded this trough. At times the water at certain localities was comparatively free from sediment. There a multitude of corals and other lime-secreting animals and plants were busily engaged in building reefs and platforms upon which to dwell. Thus layers of limestone alternate with sandstone and shale in the rocks undergoing deposition. Most of these rocks were deposited in very shallow water, for the surfaces of many beds are ripple-marked, or display the tracks and trails left by animals crawling over the moist sands of the shallow sea floor.

Apparently the floor of this trough must have been repeatedly lowered, because at some places the layers of sediment total more than 25,000 feet in thickness. Presumably also the land mass of the Older Appalachians was repeatedly uplifted as its surface was worn away.

Sketch by Edward A. Schmitz.

FIGURE 59. The Delaware Water Gap resulted from the superior resistance of the rocks which compose Kittatinny Ridge. When the streams were eroding their courses below the peneplain represented by the smooth crest of the ridge, they easily excavated the weaker formations on either side but left the strong rocks standing as a barrier across the Delaware Valley.

These movements were occasionally accompanied by volcanic eruptions, involving the intrusion of molten lava into the outer crust beneath the Older Appalachian lands, as well as the explosion into the air of considerable quantities of volcanic débris. Such activity was especially pronounced in the northern part of the area. It was during one of these episodes of volcanic activity that the Quincy granite and the granite of the Blue Hills was formed by the crystallization of lava which had welled upward into huge lava chambers a few thousand feet below the surface of the ground. Under such conditions the lava cooled very slowly and the large crystals of the coarse-grained granite were given time enough to form.

Late in the Paleozoic Era the Appalachian trough was so nearly filled with sediment that it changed from an open sea-way into a series of swamps and marshes clogged with vegetation. Large quantities of peaty material accumulated in these swamps, just as it is now doing in the Everglades and the Great Dismal Swamp of Florida. At many places the peat was buried beneath sand or mud, as a result of slight oscillations of the sea level. Thus preserved from decay, the vegetation of the Paleozoic swamps was gradually transformed into coal. In consequence the younger formations of the Newer Appalachians and of the Appalachian plateaus include many coal seams, one of the most valuable of the resources of this era.

Just about the time that the coal was being formed, or possibly a short time after that, there occurred a world-

wide change of climate. It was a time of severe chilling of the earth's surface, a refrigeration such that great ice-sheets were formed upon several of the continents. North America seems to have escaped with a minimum of glaciation during this ancient ice age, but at least one small ice-sheet was formed here. At Squantum Head and elsewhere in the immediate vicinity of Boston there are rocks consisting of pebbles and bowlders embedded in finely pulverized rock flour and associated with seasonally banded clay slate. Some of the bowlders in this conglomerate display markings characteristic of glacially transported stones. It is evidently a portion of an ancient glacial moraine, long since cemented firmly into solid rock. This is not the well-known Roxbury "puddingstone" conspicuously displayed in the southern half of the Boston Basin, although that conglomerate was formed at about the same time. The Roxbury conglomerate was deposited by swift streams vigorously eroding a rather rugged land mass and transporting their burden to basins at the foot of hills and ridges.

This long interval of sedimentation was brought to a close by the horizontal compression of this entire area. The Older Appalachian land mass was pushed bodily northwestward against the interior of North America. Caught as between the jaws of a closing vise, the Appalachian trough was crumpled and mashed into a series of complicated folds. A strip of the earth's crust more than 2000 miles long and at least 400 miles wide was squeezed into a width of about 270 miles. At places the

tremendous stresses involved in this mountain-making episode were relieved by the fracturing of the earth's crust and the overthrusting of one segment upon another. It was during this, the so-called Appalachian revolution, that the long narrow folds of the Newer Appalachians were made when the formerly horizontal layers of rock wrinkled and bent under the strain. At the same time the entire Appalachian region was bodily uplifted so that the summits of the new-born ridges stood many thousands of feet above sea-level.

The rocks which yielded to these tremendous strains were, of course, greatly changed in the process. At some places the limestone became marble, sandstone was changed into quartzite, and shale into slate. Most important from the human point of view was the effect upon the coal seams. Some of the coal swamps were in the crumpled zone; others lay farther west, in the region which now comprises the Appalachian plateaus. Where the pressures were comparatively slight, bituminous coal was formed, but the same sort of peaty vegetal material in the localities of intense pressure and close folding was changed into anthracite coal, as the more volatile gases were driven out and the whole rock was made harder and more compact. Most of the anthracite coal was worn away during the subsequent erosion of the Newer Appalachians, but a small percentage has been preserved in certain of the downfolded troughs in eastern Pennsylvania, the region from which almost all the hard coal now being mined in the United States is obtained.

There were similar coal-forming swamps in New England — one in the general vicinity of Worcester, Massachusetts, and another in the Narragansett Bay region. Here, however, the pressures were greater and the folding even more intense than that which occurred in Pennsylvania. In consequence the transformations went beyond the desired point. The vegetal material was changed into graphite and graphitic coal, containing so little volatile material that it will burn only at extremely high temperatures. Old Mother Earth had overreached herself; a good thing had been pushed too far. The resulting layers of graphitic coal have very little value and cannot now be utilized economically. Had the squeezing of southern New England been a little less intense, there would be anthracite coal fields in Massachusetts and Rhode Island similar to those in Pennsylvania.

As soon as the Appalachian revolution had lifted and pushed this region above the general level of its surroundings, it was immediately subjected to vigorous erosion by the streams coursing swiftly down its slopes. Rivers gnawed deep canyons in the youthful ridges, and channels were lowered until a gentle gradient was reached. As time went on, the canyons were broadened into wide valleys and the higher divides and ridges were worn down. Before the end of the next geologic era the first generation of the Newer Appalachians had practically disappeared, and instead of rugged mountains, the area appeared as an undulating plain. Such a surface, which has been eroded down until it is about as near to sea-

FIGURE 60. Mount Chocorua is one of many monadnocks in the White Mountains of New Hampshire, which stood high above the peneplain developed in the Appalachian region during the Mesozoic Era.

level as running water can wear the land, is called a peneplain (almost a plain). The Older Appalachians with their stronger rocks proved much more resistant to erosion. The crust above the great masses of crystallized lava was largely worn away, but the crystalline rocks themselves were so difficult to erode that they remained standing high above the adjacent lands, even as the Berkshire Hills stand to-day above their surroundings.

Thus, toward the close of the Mesozoic Era, the Appalachian region presented a very different appearance from that which may be seen to-day. Where now are the White Mountains, the Green Mountains, the Unakas, and the Great Smokies, were rugged hills one or two thousand feet high; but nearly everywhere else throughout the eastern part of North America there stretched a low undulating plain comparable to the prairies and hills of Illinois and Indiana. Mount Monadnock then rose in solitary grandeur a few hundred feet above the surface of the surrounding peneplain. Its name has been borrowed by geologists, and any isolated hill standing as an erosion remnant above a peneplain is now known as a monadnock.

Late in the Mesozoic Era, perhaps eight or ten million years ago, this ancient peneplain was bodily uplifted and arched into a broad low fold, the summit of which was two or three thousand feet higher than the lands on either side. The streams which had been lazily meandering across the flat lowlands were quickened where they flowed down the flanks of this great arch, and imme-

diately they began to cut their way downward toward a new base-level. The story of this sculpturing of the present mountains is a complicated one. It involves at least three episodes of renewed uplift, followed by vigorous downward erosion.

Before the Mesozoic peneplain was elevated, the larger streams of the Appalachian region were flowing without much regard for the differences in strength of the rocks along their courses. When a mass of rocks of differential resistance to erosion has been worn down to a low flat plain, the larger rivers are no longer engaged in cutting downward into the underlying rocks. Therefore they flow across strong or weak beds with equal facility. But when a lowland plain is uplifted and transformed into a plateau, the streams begin anew the task of downward erosion. Their channels are cut deep into the plateau, as the new and lower grade is attained. At this time the varying resistance of the rocks becomes very important, and so far as possible the rivers adjust their courses by concentrating their work in the areas of weaker formations, where erosion goes forward more rapidly and easily than among the rocks which offer the greater resistance to wear. Thus the stream courses are shifted; valleys appear where rocks are weak, and the strong beds are left standing as ridges or hills above their surroundings. In the Appalachians, the long, smooth-crested ridges are formed of strong sandstone or other sedimentary rocks which have not yet been reduced by stream erosion. Their crests are remnants of the former lowland plain developed during the Mesozoic Era. The

FIGURE 61. The lure of mountain scenery and the sense of kinship between man and Old Mother Earth are reflected in Odell Shepard's poem, "Whence Cometh My Help":

Let me sleep among the shadows of the mountains
when I die,
In the murmur of the pines and sliding streams,
Where the long day loiters by
Like a cloud across the sky
And the moon-drenched night is musical with dreams.

I am what the mountains made me of their green and gold
and gray,
Of the dawnlight and the moonlight and the foam.
Mighty mothers far away,
Ye who washed my soul in spray,
I am coming, mother mountains, coming home.

valleys are carved in the weaker rocks where the streams concentrated their activity following each vertical uplift of the area.

Although the smaller streams of the Appalachian region succeeded nobly in adjusting their courses to the underlying rock structure, the master rivers were unable to do so. The Delaware River is an excellent illustration of a stream which follows a course inherited from the time when it meandered lazily across the Mesozoic plain. When the region was elevated, a deep canyon was cut into the former valley floor. This canyon was readily broadened into a wide valley where the rocks were weak, but the strong rocks still rise steeply from the narrow stream bed and form short but picturesque gorges like the Delaware Water Gap.

Thus the Appalachian region was made ready for the coming of mankind. The first white settlers in this area found a wilderness of forest-covered hills and ridges. For a long time the western movement of the American colonists was hindered by its rugged barriers, and communication across the roughest sections is still difficult. In the more remote coves and valleys the mountaineers still follow customs of a half-century ago. In the larger and more accessible valleys the agricultural and mineral resources have made possible the most remarkable industrial development of which we have any knowledge. The obstacles and opportunities provided by Old Mother Earth in the Appalachian area have challenged men to their best endeavors and have developed a hardy race of energetic and efficient individuals.

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